METALS AND ALLOYS

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TREATMENT APPLICATION

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For Economical STEEL ANALYSIS...

NORTON COMBUSTION BOATS AND RR ALUNDUM GRAIN

IN the plants of both the steel maker and the steel user, careful and frequent analyses are important. For years Norton Combustion Boats and RR Alundum have been popular with metallurgists for carbon determinations. Three types of Combustion Boats meet different conditions and preferences — and save costs because of their long life. RR Alundum is available in two grades (Blue Label and White Label) and is now packed in 25 and 50 pound packages for large users, at new low prices.

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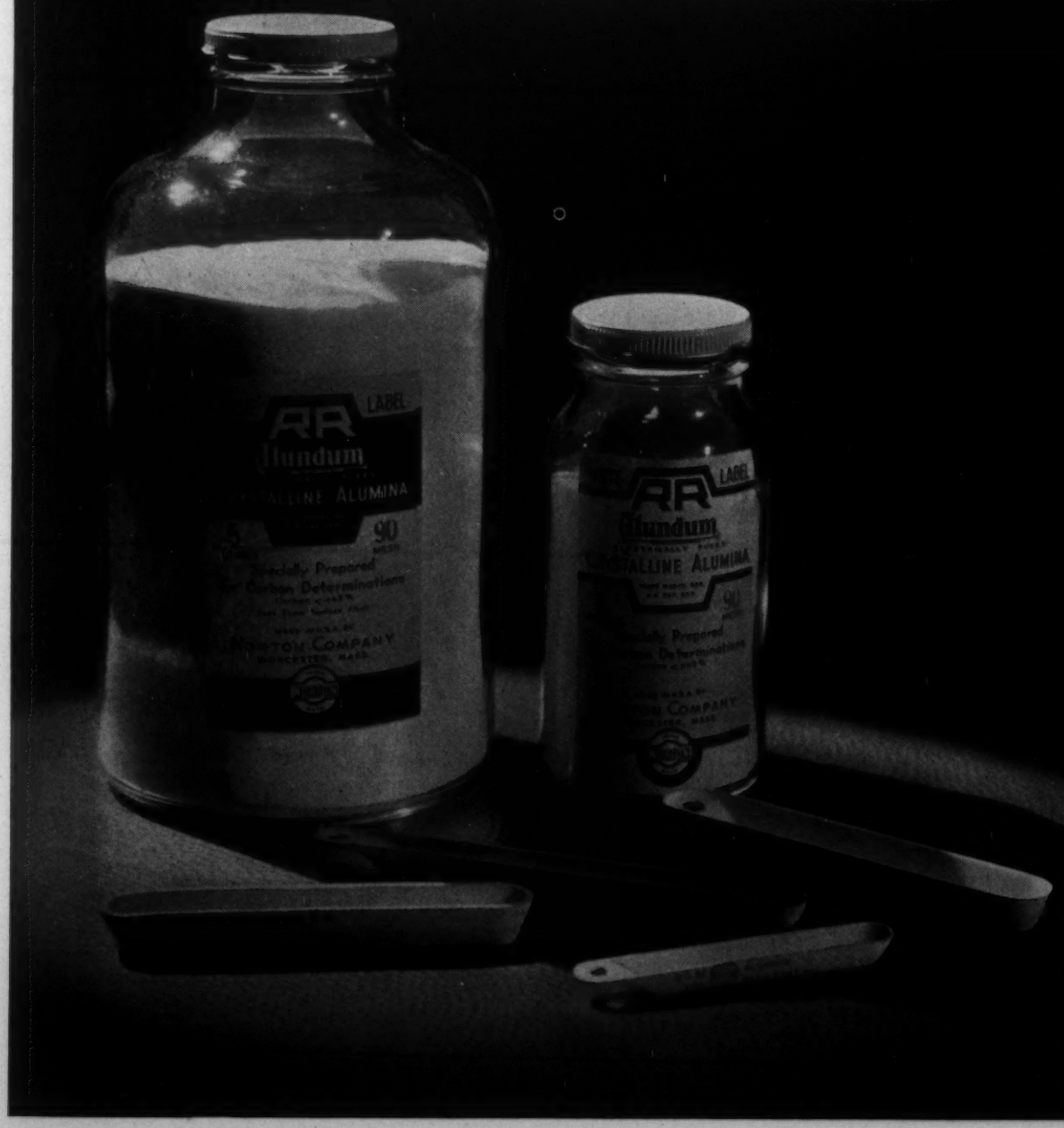
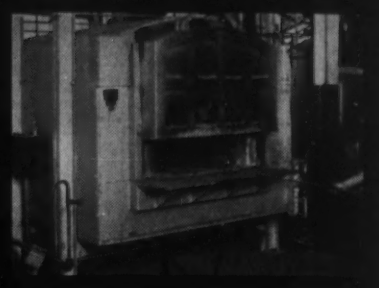
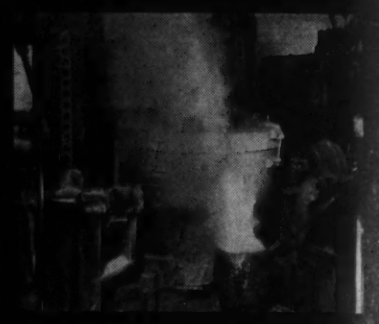
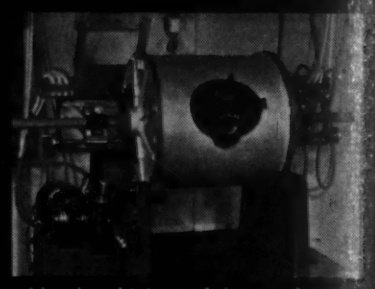




Crystolon Plates (silicon carbide) fill the need for a heavy duty refractory hearth in heat treating furnaces of American Electric Furnace Company and others. The strength, refractoriness, high heat conductivity and resistance to abrasion of Crystolon Plates make them outstandingly economical.



Norton Magnesia Cements are universally used in the lining of Ajax-Wyatt furnaces for melting high copper and nickel silver alloys. Recent Norton developments have resulted in cements that give even longer lining life.



Alundum Linings of the crock type have been extensively used by Detroit Electric Furnace Company in their furnaces, particularly in the melting of non-ferrous alloys. In this application Norton Refractories are rendering valuable service and lowering costs.

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If you are operating furnaces for melting or heat treating metals it will pay you to consider Norton Refractories. Three materials — Alundum (trade-mark for fused alumina), Crystolon (trade-mark for silicon carbide) and Fused Magnesia — each with different chemical and physical properties, make it possible to meet widely varying conditions, to reduce costs for many concerns. Let Norton engineers consider your jobs.

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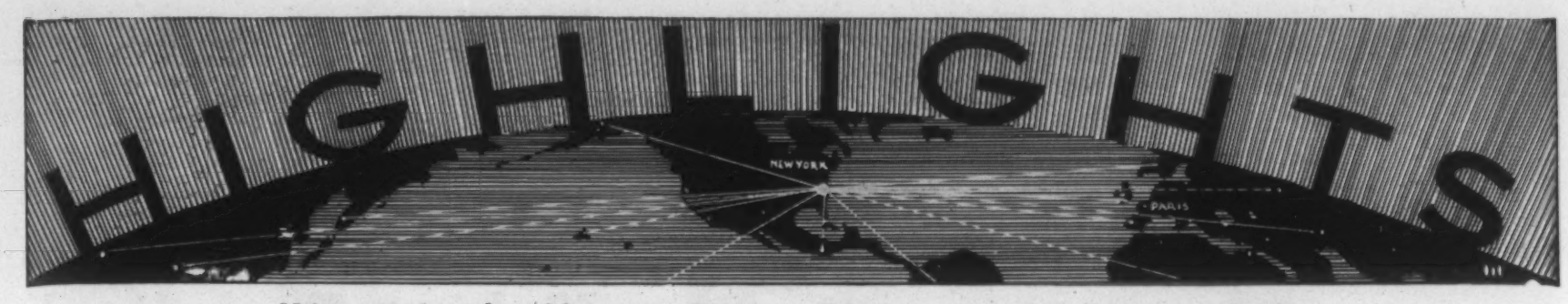

Written by the Abstract Section Editors and the Editorial Staff

DO YOU want to know what metallurgical engineers are saying, the world over? Look in the Current Metallurgical Abstracts. Here are some of the points covered by authors whose articles are abstracted in this issue.

How Deposits of Sulphur Are Formed

When a tank containing liquid sulphur, superheated water, and rocks, is opened at the bottom, pure sulphur emerges first, although it is lighter than the rocks. A. J. Crowley has an explanation for this which clarifies our picture of the formation of sulphur deposits underground (page MA 487 R 4).—J. G. A.

Foundrymen, Attention!

The abstracts in this issue contain an unusually large number of items dealing with the production and properties of various types of cast iron (page MA 489 L 1, L 2, R 1, R 3; page MA 490 L 6, L 9, R 1).—C. H. H.

Really Pure Iron?

We still do not know the properties of really pure iron, since it has never been prepared, but Thompson and Cleaves (page MA 490 R 3) give a summary of methods of preparation and properties of iron that ordinarily would be considered quite pure.—B. W. G.

Heat Treating Springs

Springs form important parts of many machines and are subjected to millions of cycles of stressing, in some cases to both corrosion and repeated stresses. The treatment of main springs for clocks and gramophones is discussed by Tingle (page MA 494 L 2). The application of the electric furnace to the heat treatment of springs is advocated by Goddot (page MA 494 R 2), and Fomin and Berner (page MA 494 L 10) discuss the effects of chemical variations in silicomanganese spring steels on the physical properties.—O. E. H.

A Scale for Measuring Inclusions in Steel

The Swedish Ironmasters' Association has prepared a series of photomicrographs, carefully graded, by which one may classify slag inclusions in steel according to their formation, distribution, and quantity. A set of these standards, together with instructions in English, are available (page MA 502 L 3).—C. S. B.

Automobile Parts

As is well known, the automotive industry has been a leader in applying research to the development of better heat-treated parts. An unusual heat treatment for axle shafts is described by Allen (page MA 494 L 3); Lobanov reports the cause of trouble in heat treating drive gear parts (page MA 494 L 4); Fomin and Berner (page MA 494 L 9) point out that slight variations in analysis of automobile frame steel make it necessary to classify the stock and use different heat treatments; and Davis (page MA 494 R 4) outlines the production and requirements of modern gears.—O. E. H.

Grinding versus Burnishing

One finds it hard to reconcile the claim made (page MA 500 R 10) for longer life of driving axle journals that have been finished simply by grinding, as compared with those which have received a burnish finish, with our general knowledge of the effect of surface finish on endurance or fatigue of metal parts. Grinding is in use by the Canadian National Railways, whereas the accepted method in this country is burnishing.—H.S.R.

Bright Plating

The production of coatings by electroplating which are so bright, smooth, and lustrous as to render buffing and polishing unnecessary is one of the recent outstanding accomplishments in the plating industry. One of the most recent attempts along this line is in cobalt plating (page MA 501 L 2). The basis on which the investigator proceeded was that the matte or dull surface of a plated coating is associated with the presence of traces of hydroxide or basic salts built into the structure of the deposit and the purer the metal the better the chance of producing a bright lustrous surface. With this working hypothesis, some very satisfactory results were obtained.—H. S. R.

Paint on a Galvanized Surface

It is well recognized that a galvanized surface should not be painted until it has had a chance to weather or has been chemically treated so as to increase its paint-holding properties. Basic information on the reason for this undesirable behavior of paint on zinc is very scanty indeed. It has been recently shown, however (page MA 501 R 3), that the oxidation products formed by the drying of the paint oil react with the zinc and compounds, such as zinc formate, resulting from such a reaction have been isolated in paint films which have peeled off from galvanized surfaces. This may be the start in the development of a non-peeling paint.—H.S.R.

A Check-Up on Stress Measurements

Two different methods of measuring stresses in quenched steel shafts were compared recently—the X-ray method and the mechanical method of Sachs. The methods were in excellent agreement when the offending outer layer of the shaft was etched off. This layer contained stresses visible to the X-ray but hidden from the mechanical test (page MA 502 L 5).—C. S. B.

We Raise a Question!

It has been proven time and again and emphasized repeatedly that corrosion test conditions should be as near service conditions as it is possible to get them. Why, therefore, if you are testing pipe coatings for resistance to presumably soil conditions and you go to the trouble of testing in sulphuric acid, hydrochloric acid, ammonia, caustic soda, sodium chloride, sulphurous acid, phosphoric acid, fresh water and sea-water—why don't you include a few soils? Of course, we know that there are some 1,500 different soils in the U. S. alone, but the Bureau of Standards did very well with 47 of these and from their data we could pick half a dozen that would tell the whole story from a protective coating standpoint. Exposure to a few soils would surely give you more valuable information than exposure to various chemicals (page MA 508 L 2).—V.V.K.

How's Your Skin?

Briggs and Gezelius (page MA 490 L 9) have been able to predict the rate of skin formation in various sizes of steel castings. Six important points are discussed.—C. H. H.

Effect of Flame Cutting on Steel

The A. S. M. E. Boiler Code Committee recently conducted an investigation of the conditions which develop when the fusion welding process is applied to a flame cut edge. As a result, all restrictions in the Boiler Code pertaining to welding on surfaces so prepared have been removed. The rules now state that plates may be cut to size and shape by a flame cutting process, provided the carbon content of the steel does not exceed 0.35 per cent. These rules stipulate further, however, that flame cut plate edges must be uniform and smooth and that all loose scale and slag accumulations must be removed from them before welding. It is expressly stated in the Code that the discoloration which may appear on flame cut surfaces is not considered to be detrimental oxidation (page MA 498 L 6).—E. V. D.

Achievement!

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Our Section Editors

(Continued from the July, August and September Issues)

C. H. HERTY, Jr. is a research engineer in the Development and Research Department of the Bethlehem Steel Co., Bethlehem, Pa. He was born in Athens, Ga., and obtained his B.S. in chemistry from the University of North Carolina in 1918. After a brief period with the ordnance department of the U. S. Army, he obtained his M.S. in chemical engineering from M. I. T. in 1921 and his degree of D.Sc. from the same institution in 1924.

During 1921-1922 and 1924-1925 Dr. Herty was assistant director and research associate, Lackawanna Station, M. I. T. School of Chemical Engineering Practice. From 1926 to 1931 he was in charge of a cooperative project on the physical chemistry of steel making at the U. S. Bureau of Mines, Metallurgical Division, Pittsburgh. From 1932 to 1934 he served as director of research for the Metallurgical Advisory Board at Pittsburgh, which was a continuation of his well-known work on the physical chemistry of steel making. He assumed his present position in 1934.

C. H. HERTY, JR.

Dr. Herty has had several honors conferred on him. He was awarded the Hunt Prize of the A.I.M.E. in 1928; he was the Campbell Memorial Lecturer for the A.S.S.T. in 1931; and the Clamer Medal was awarded to him in 1935 by the Philadelphia Technical Society. He is a member of the A.I.M.E., the A.C.S., and the A.S.M.

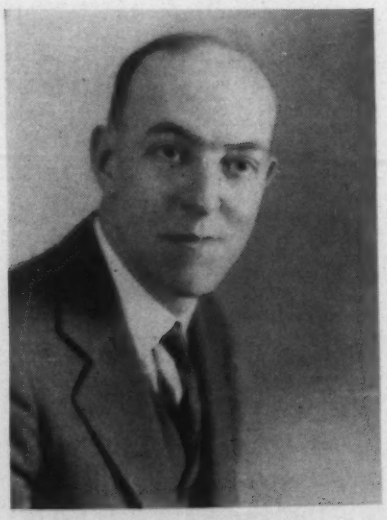
JOHN S. MARSH is physical metallurgist and associate editor of the Alloys of Iron Research of the Engineering Foundation, 29 West 39th Street, New York. He received the degree of B.S. from Penn State College in February, 1927. He remained there for graduate work in physical chemistry until the following September.

For the next year and a half

J. S. MARSH

Mr. Marsh was connected with the Aluminum Co. of America. After a year's interlude with the Keuffel & Esser Co., he became associated with the Alloys of Iron Research during its early days. Activity there has included authorship of several monographs of the series.

V. V. KENDALL is a metallurgist and chemist with the National Tube Co., Pittsburgh, working on corrosion and allied



V. V. KENDALL

problems. He has three degrees: A.B. from Missouri Wesleyan College; B.S. in Education and M.A. in chemistry from the University of Missouri.

Previous to the assumption of his connection with the National Tube Co. in 1922, he was assistant chemist for the Missouri, Kansas & Topeka Railway; head of the chemistry department of Daniel Baker College, and research associate in the research laboratory of applied chemistry of the Massachusetts Institute of Technology. During the war Mr. Kendall was connected with the chemical warfare service, research division of the United States Army. During the past year he conducted a night school course in the corrosion of metals at the Carnegie Institute of Technology.

M. H. MAWHINNEY was a partner in the Salem Engineering Co., Salem, Ohio, designers and builders of industrial furnaces, from its formation in 1934 until July of this year. He is now engaged in private consulting practice in Salem. He was graduated in 1921 from the Carnegie Institute of Technology. In 1922 he was associated with

M. H. MAWHINNEY

Professor Trinks of that institution. He obtained his M.E. degree from Carnegie in 1923.

After being associated with the Jones & Laughlin Steel Co., Pittsburgh, during 1923, he became connected in 1924 with Tate-Jones & Co., Inc., Leetsdale, Pa., furnace builders. In 1925 he became chief engineer of this company. Later positions include one with the General Furnace Co., Philadelphia, and with the Gas Equipment Co., also of Philadelphia, 1926 to 1928. From 1928 to 1934 Mr. Mawhinney was in charge of the fuel division of the Electric Furnace Co., Salem, Ohio.

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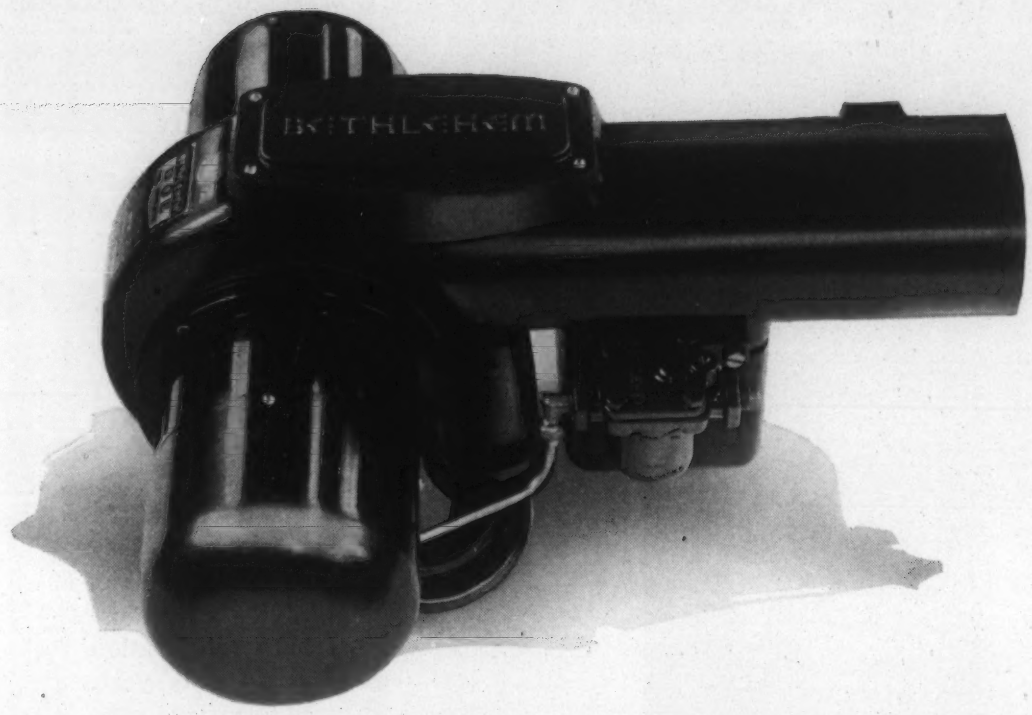

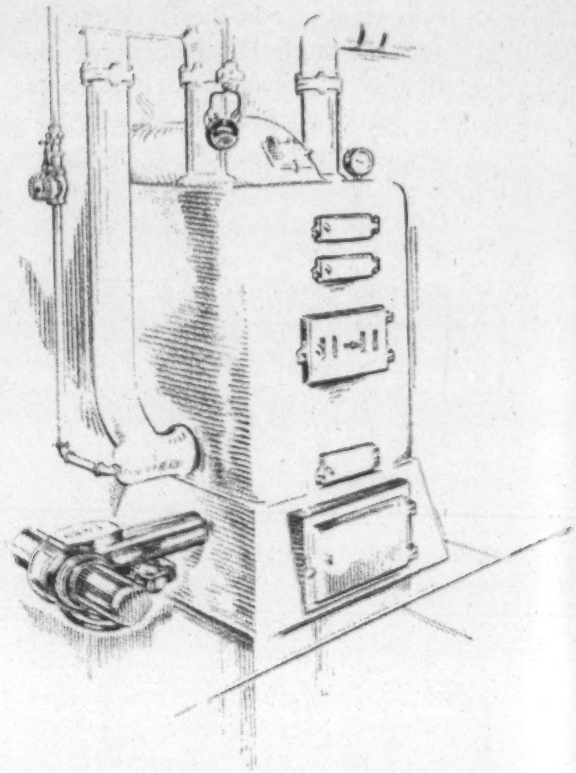

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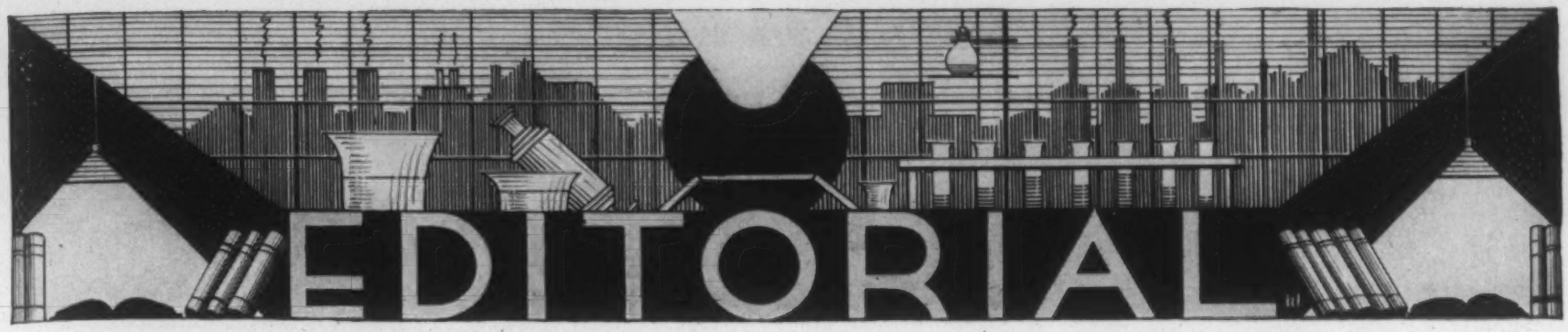


The Second Team

THERE used to be a theory, doubtless erroneous, that every seven years the body was entirely changed, every atom having been eliminated in that period, and replaced by a new one.

At any rate, very considerable changes can, and often do, occur in such a period. The active leadership in any given organization is quite likely to shift, people down the line change jobs, and in general new blood makes its appearance.

It is now something over seven years since METALS & ALLOYS began publication. Looking back at metallurgical engineering for that period, we find no very great shift. A few of the younger men of promise have fulfilled that promise and taken their places along side the older leaders, but relatively few of the latter have died or become inactive. We have lost from our own Editorial Advisory Board, largely made up of men of maturity, Spring, Bassett and Mathews.

Of the earlier leaders, Howe and Campbell passed on before the period under discussion, but their students are still in their prime. As a matter of fact, scientific metallurgy is so new that Sauveur, the Dean of Metallurgists, can quite truly say "all of which I saw, much of which I was." It is only 50 years since the first heat of basic open-hearth steel was made, the same time since the first electrolytic aluminum was made, and, as Sauveur ("A Review of Progress in Ferrous Metallurgy," *Steel*, July 6, 1936, pages 38-42) points out, 1936 also marks the 50th anniversary of metallography while the thermocouple still lacks a year of having attained the half-century mark.

Under such circumstances it seems probable that next few years will see the passing, from the active stage, of many of our present most mature leaders in scientific metallurgy and the filling of their places by the younger generation. It may be a brutal way to look at it, but we wonder if various technical committees and technical societies as well as commercial organizations, shouldn't be warming up the second team. —H. W. G.

Pet Peeves

WE read our wife's copy of the *Journal* of the American Association of University Women with some interest as showing the sort of thing these highly educated women are interested in as a body. Most of the uplift stuff they deal with seems pretty futile, perhaps the prize being taken by that chapter of the Association which is preparing a skit to be given before the boys in the C.C.C. camps on how to escort a girl to a movie.

However, once in a while, they copy an article from an outside source or record an address that contains some food for thought. The June issue contains an article by E. L. Thorndike, "The Goal of Social Effort," in which he (we guess it's a he) sets forth "specifications for a good life for the human species," with 26 items in the specifications.

We pass over those for food, shelter, human companionship, etc., which anyone would cite, but note with special approval item 13 which indirectly includes keeping a dog, and item 25, "Freedom to Discover and Publish Verifiable Truth." It is item 23 that hits a specially responsive chord, "Something to be Angry at and Attack."

Thus, at last, we find something useful in the New Deal! But after November, when the New Deal shall have been properly interred and the New Dealers been relegated to oblivion, we will have opportunity to consider other things that should be exterminated.

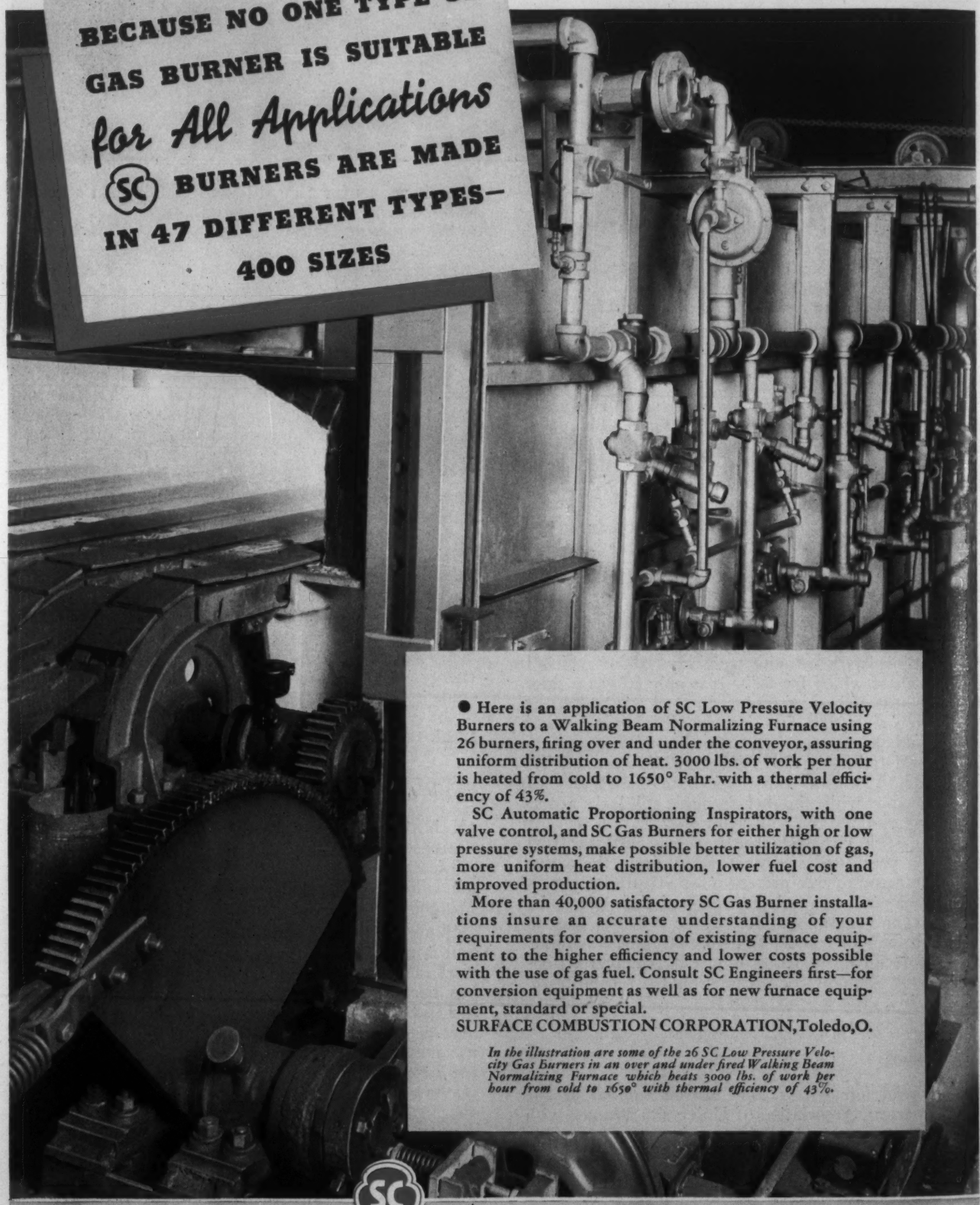
On our personal list we have the writers who convert a rounded Centigrade temperature to its exact Fahrenheit equivalent, like the case recently noted in a metallurgical trade journal where the available temperature of a furnace being described was stated as "about 3272 deg. F." and the pouring temperature for steel as "3002 deg. F.;" those who still refer to fatigue failures as "crystallization under repeated stress;" professors of technical subjects who maintain no contact with industry; other professors who put all their energy on consulting work with none left for their students; and the self-advertising scientists who ask to be put on committees and to be seated at the speakers' table.—H.W.G.

Lead 'em

IN bird hunting or skeet shooting, most birds are missed by shooting behind them. One may get a few tail feathers, but the bird flies on, unless you have shot, not where he was when you saw him, but where he was going to be. And you can't eat tail feathers.

Similarly, much of our industrial research information is too late, like the patents for free-wheeling devices that only mature into patents after free-wheeling has become obsolete. Detailed studies of processes and products that have been supplanted by others before the information on the older ones is ready to use may be interesting but are seldom valuable. In the case of a university research problem, the professor consoles himself with the thought that the work was just as good training for the student, but the director of research in an industrial organization can summon no consoling thoughts.

It uses just as much powder and shot for a miss as for a hit. The projects that count in the score are those where, as much by intuition and practice as by conscious aiming, the gun has been so pointed that when the dope is collected it fills a need of that moment and not of the past. If you can gage the current of events and the progress of information as the sportsman gages the wind and the flight of the bird, he is far more likely to score a direct hit than if he takes only the present into account.—H.W.G.



● Here is an application of SC Low Pressure Velocity Burners to a Walking Beam Normalizing Furnace using 26 burners, firing over and under the conveyor, assuring uniform distribution of heat. 3000 lbs. of work per hour is heated from cold to 1650° Fahr. with a thermal efficiency of 43%.

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METALLURGY OF RAIL STEELS

Developments in Last 25 Years

A Correlated Abstract

By H. W. GILLETT

IN 1911, A QUARTER OF A CENTURY AGO, the Manchester railroad wreck occurred which made transverse fissures a burning problem for railroad maintenance men and for the metallurgists of the rail producers. Howard's report on the causes of the wreck precipitated a long discussion as to whether the fissures were due to any causative source in the rails themselves or whether the best rail would fail under the wheel loading. While Howard took the latter view it was pretty obvious to anyone who was at all acquainted with fatigue failures that a transverse fissure is a fatigue failure, and that such a failure has a nucleus that acts as a starting point.

The existence, in some rails, of interior shatter cracks that occur at some time during the cooling of the rail, was brought out in 1915 by Wickhorst[1], and in 1919 by Waring and Hofammann[2]. That these cracks were the nuclei for development of the fissures seemed very probable. Hibbard[3], in the discussion of a paper by Howard in 1918, suggested slowing down the rate of cooling on the hot beds, on the theory that fissures were set up from strains induced by cooling stresses. That the cooling stresses are now known to relieve themselves by the formation of shatter cracks which are now held to act as nuclei for early fissures does not detract from the clarity of vision with which Hibbard spied out the commercial answer to the problem. It remained for others to work out the practical application of this suggestion.

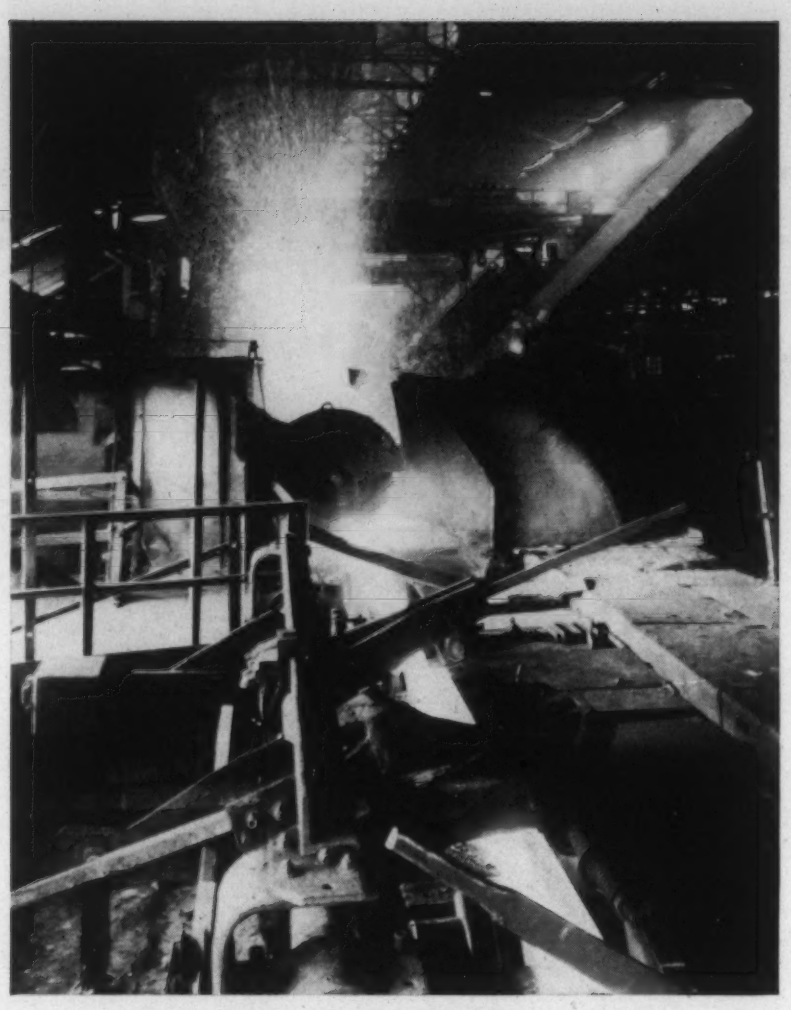
Tensile Stress in the Rail Head

Indeed some observers feel that the basic thing to be avoided is residual lengthwise tensile stress in the rail head, and that this tension may not always have been relieved by formation of shatter cracks that show when the new rail is sectioned and etched. Hence some mills are carefully observing rails on the basis of residual stress as well as on that of shatter cracks. One school of thought argues that service stresses in heavy service are above the endurance limit of the rail steel, even in rails without discrete nuclei, and that any rail not first removed from track because of wear might, after many years of service, show a fatigue failure. From this point of view maintenance of track and avoidance of flat wheels, as well as holding down the wheel loading on the one hand, and the development of rail steels of high endurance limits on the other would be correct lines of attack upon the problem of such long-delayed failures without a discrete nucleus. The ability of the steel to resist damage under a relatively small number of applications of relatively high stress, i.e., above the endurance limit, would also be a factor. This is being studied by Prof. Moore and co-workers.[20]

However, practically everyone now agrees that the fissures that appear in the early part of the normal life of the rail have as nuclei the shatter cracks or, alternatively, the excessive residual stresses that have not been relieved as shatter cracks, so that avoidance of both stresses and cracks by some method of controlled cooling is being widely introduced.

Destructive testing to pick out shatter-cracked rails may, according to the Second Progress Report of the Joint Investigation on Fissures in Rails, recently issued[6], be more effectively carried out by slow bend testing, with the head down, than by ordinary drop testing. Fig. 1 from this report is quite illuminating.

Rails in the Making in a Finishing Mill.



A Hot Saw in Action, Cutting Rails to Length.

About 10 years ago the Sperry detector method was instituted by which fissures that had grown well up toward actual fracture could be found and the defective rail removed from the track. This development was financed by the American Railway Association. The detector method is surgery rather than preventive medicine, and only handles the problem after the rail has been in service and the fissure has grown. It is essential as a safeguard against trouble in rails already laid. Only indirectly, in giving quicker indication of the heats in which shatter cracks have occurred, does it help toward the problem of keeping shatter-cracked rails out of track.

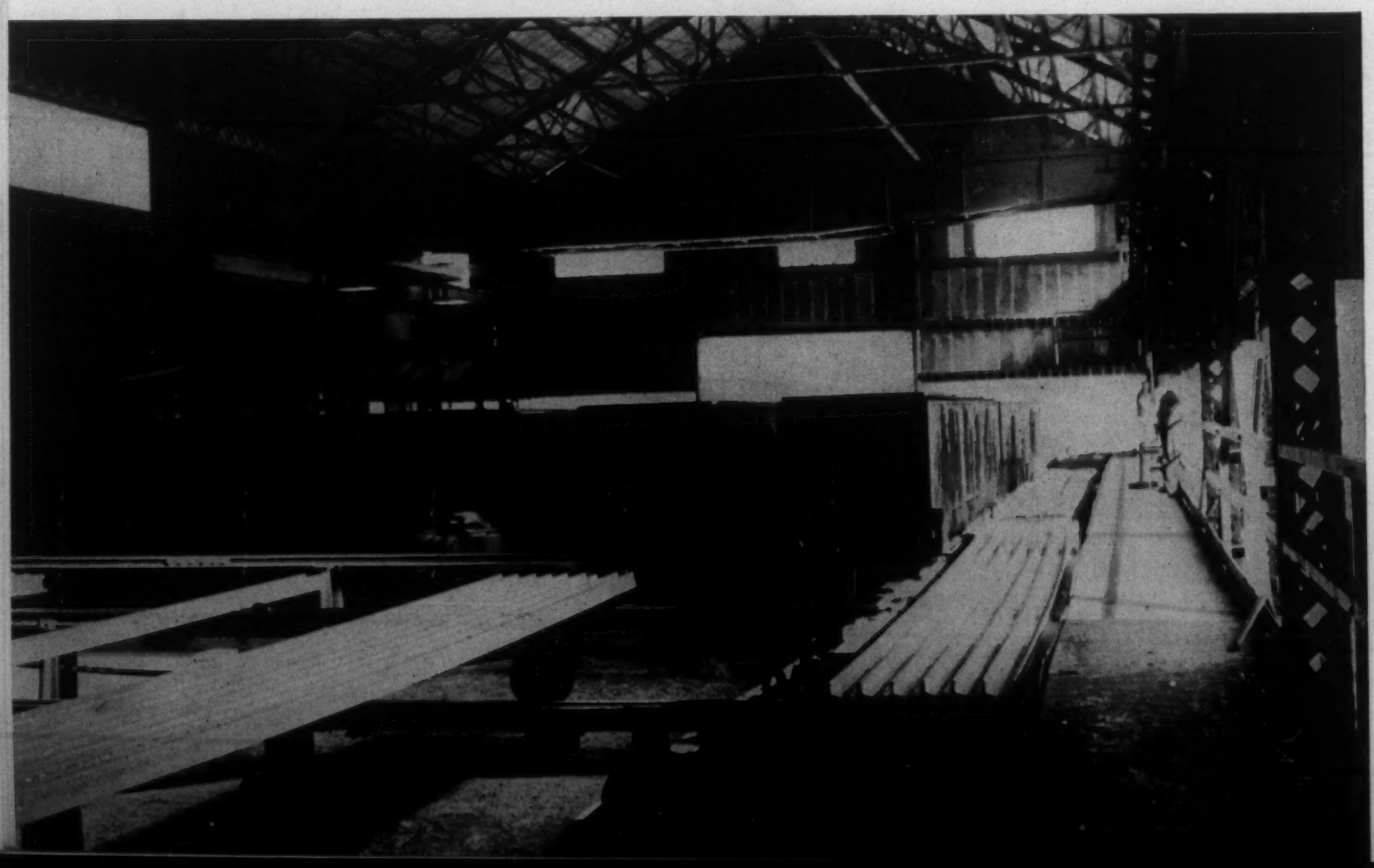
Slow Cooling Early Advocated

Long continued work at the Bureau of Standards, largely by Freeman and his collaborators[4], had brought the Bureau to the point where, in 1929 it believed that early fissures came from shatter cracks and that the cracks occurred on the hot beds. Early in 1929 it urged rail makers to experiment with slow cooling. A bit later, Sandberg, who had independently come to the same point of view and had developed practical methods for retarded cooling, came to this country to try to interest rail makers in his methods, which had been installed in Middlesbrough, England, the previous year.

Progress up to this point has been recorded by McDonnell[5] in 1929 who pointed out that at that time the railroads and the rail makers were starting to pull together and that if they continued to do so, a solution could be expected. It is pleasant to note that they have pulled together since then and that something is really being done about keeping out of the track those rails that will have fissures, as well as about taking them out after they have started to do so.

The connection between shatter cracks and early development of fissures is now quite generally accepted, as a result of the joint investigation of fissures in rails carried on under the auspices of the Association of American Railroads, the Steel Rail Manufacturers and the University of Illinois. The work of this investigation has its headquarters in the Materials Testing Laboratory of the University and the test party of some 16 persons is under the direction of Prof. H. F. Moore.

The Sandbergs discussed their method in 1931[7a] and 1932[7b] and at that time stated that the Bethlehem Steel Co. would shortly have an oven for slow cooling installed at the Lackawanna mill. A recent discussion of Bethlehem practice[18] traces the commercial development of controlled cooling of rails through the work of the Sandbergs, Mackie[8] of the Dominion Steel & Coal Corp., Sydney, N. S., and unpublished work by Gerhardt of Bethlehem to the point where a million tons of such rails have been produced in Europe and over a third of a million in the United States and Canada, Bethlehem and more recently the Inland Steel Co., and the Colorado Fuel & Iron Co., having put slow cooling



Cooling Beds with Controlled Cooling Boxes in the Background.

into production on a large scale in the United States, while the Dominion Steel & Coal Corp. is in production in Canada.

Practice in Slow Cooling

In the Bethlehem practice, the rails are cooled as usual till they are between 1000 and 930 deg. F., then placed in tight insulated boxes where they stay till they have cooled below 400 deg. F. In this way better ductility and a better bend test, as well as avoidance of shatter cracks are obtained without sacrifice of hardness.

Only something like one heat of rails in 50 subjected to ordinary hotbed cooling develops shatter cracks. However, a larger percentage of heavy rails develop shatter cracks than is the case with light rails. The metallurgist at once wonders why one cannot make the 50th heat like the other 49. Removal of fissured rails by way of the Sperry detector was one step. Slow cooling of all heats to take care of the erring 2 per cent is another, and it may be cheaper, as Humfrey[21] says, to slow cool to correct this 2 per cent than to apply earlier precautionary measures that would avoid the necessity.

However, it is a challenge to the metallurgist not to know *why* the 2 per cent act as they do, and not

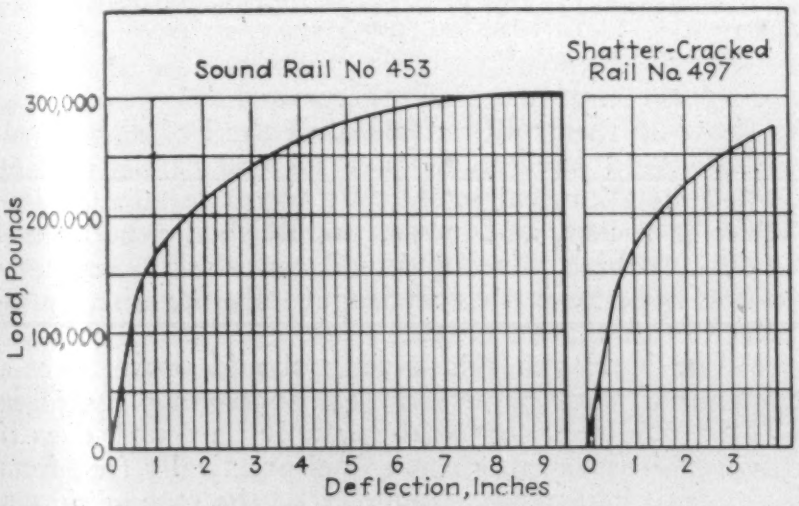


Fig. 1. **Load-Deflection Curves. Binding test on rails.**

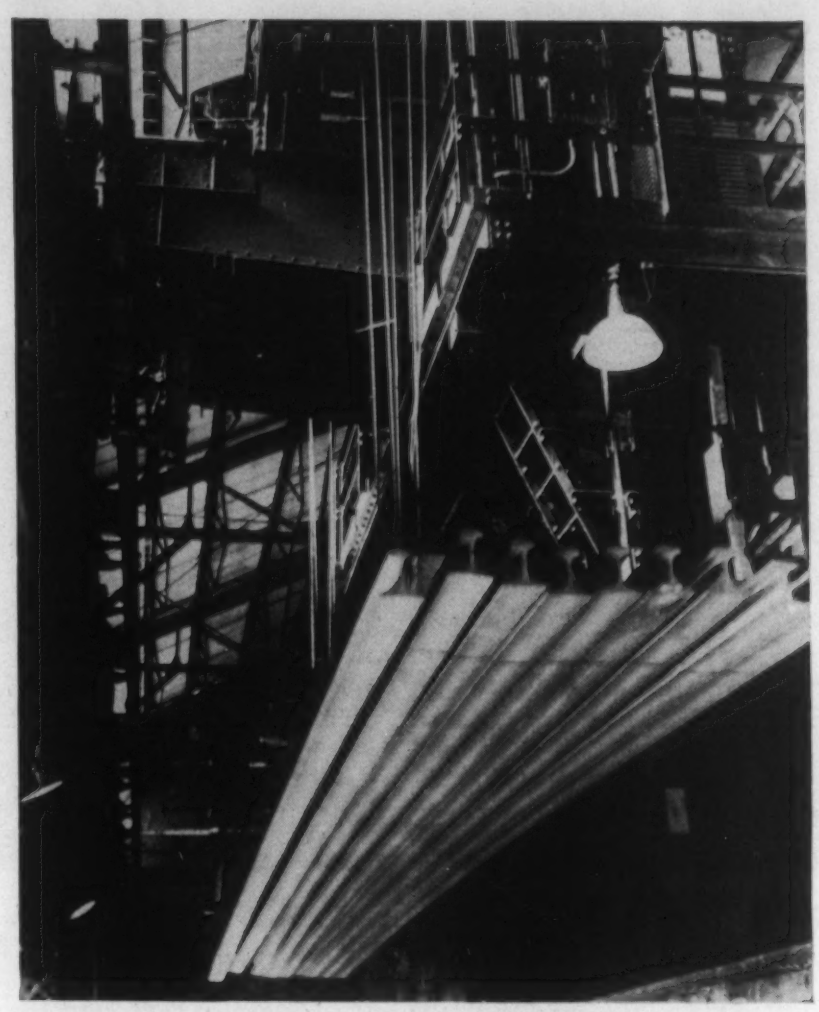
to be able to apply earlier precautionary measures, should it prove wise to do so. Moore says that an extensive study of mill conditions and records has shown no one feature of mill practice or metallurgy which can be assigned as the cause of shatter cracks. In the Second Progress Report he emphasizes the complexity of the mill problem.

Some mills think that rolling procedure is of prime importance and that, with suitable attention to this, slow cooling could be dispensed with.

Flaky Steel and Hydrogen

Epstein[9] has pointed out a possible relationship between melting practice and shatter cracks. A phenomenon somewhat analogous to shatter cracks is "flaky" steel, and there is evidence worthy of respect that flaky steel is tied up with the presence of dissolved hydrogen. Cramer[10] and Humfrey[21] bring up further evidence in line with Epstein's assumption that shatter cracks may be associated with the taking up of hydrogen in melting.

Since the fuels used in the steel mill contain plenty of hydrogen, water vapor is always present in the open-hearth furnace and the soaking pit atmosphere and it can react with the steel to form iron oxide and free hydrogen.



Transferring Rails to Cooling Boxes.

Due to a delayed boil or some other cause, one heat out of 50 might happen to be partly bare of slag at some period in the heat when the temperature was just right, or there might be some stage occurring under exceptional conditions in which the slag becomes unduly pervious to water vapor. Or it might be that

End View of Cooling Boxes.

Welded Track on the Delaware & Hudson at Albany, N. Y., Where the Longest Continuous Rail is 2700 Ft. in Length. (Courtesy Metal & Thermit Corp., New York.)

hydrogen is always taken up but ordinarily removed in the usual finishing practice.

If a heat melts down so that an uncommonly small amount of oreing down is required, the removal of hydrogen might not occur. It is doubtful if the usual furnace log would reveal clearly the variables in melting and finishing practice that might affect hydrogen absorption and retention. Experimental work aimed to show up the truth or falsity of the hydrogen hypothesis would have to be planned and carried out by skilled metallurgical talent, but adequate talent exists. There is recent, and as yet unpublished experimental evidence, which if verified, will considerably strengthen the hypothesis that hydrogen is quite directly involved with shatter cracks.

If the hydrogen relationship should prove to be a controlling factor, means for controlling hydrogen pick-up or retention could probably be found, even if it were necessary to go to a fuel practically free from hydrogen, though the economics of the case might not make this last resort a practical solution.

At any rate, a good deal of progress has been made in the attack upon rail failures from transverse fissures. A general discussion[22] of this problem has recently appeared. It is very fortunate that there has been progress, else the modern high speed passenger trains would not be feasible, for no one would care to ride on such a train over a rail that was developing transverse fissures, and he'd feel happier to know that such rail was not being laid at all, rather than merely being caught by the Sperry car at some stage of development.

As it happens, the high speed train is almost necessarily one in which the wheel loads are relatively light in comparison to those of older cars and locomotives, so that fissure development is unlikely to be much more rapid than under the older conditions. Extensive field tests by Thomas and Roy[6] of the Joint Investigation staff have shown that flat spots on freight car wheels and uneven stiffness of track are common causes of abnormally high wheel pressures on rails. Laboratory tests[6] have shown the spread of a fissure is started by the complex stress in the rail directly under a wheel, rather than by flexural stress. A given wheel pressure is as likely to *start* a spreading fissure in a heavy shatter-cracked rail as in a light shatter-cracked rail. After a fissure is started, bending of the rail, as from poor road-bed conditions, helps it to propagate.

At Schenectady, on the Delaware & Hudson, the Welded Track Consists of One Stretch of Continuous Rails 7000 Ft. Long Joined to Another Stretch 5000 Ft. Long by Ordinary Insulated Rail Joints. (Courtesy Metal & Thermit Corp., New York.)

Wear and End Batter

Reduction in wheel loads is fortunate also in regard to another rail problem which troubles maintenance men—that of wear. Wear does not progress so rapidly as to involve any notable hazard to safety, but scrapping rails from wear does involve expense. There are two types of wear that affect rails—one the actual removal of metal, most noticeable on curves, and the other a peening down of the rail end as the wheel passes over the rail joint. The latter is more properly termed "end batter" than wear, but the two are often considered together, especially since a harder rail surface serves to delay both troubles.

End batter is not only an economic problem involving too early replacement of the rail, but it also has a distinct bearing on the riding comfort of the passengers, for a smooth track makes for a pleasant ride, and this is especially noticeable at high speeds.

End batter is handled mechanically by stiffening the joint[11] so as to make the rails act more like a continuous rail, and recently by actually making it a continuous rail, utilizing the sensible idea that to minimize end troubles one should minimize the number of ends. This has been carried to the extent that already continuous rail lengths well over a mile long have been welded up and laid[12]. The expansion and contraction difficulties one might expect do not seem to have developed in actual service.

When short rails are used, the worn ends are sometimes built up in place by welding on metal and grinding it down, much as is regular practice on street railway systems. In preparation of the track to take high speed trains, one Western railroad built up all battered rail ends by welding, peening and grinding[13]. The rapid cooling by the mass of the rail gave conditions somewhat analogous to quenching. This, plus the peening, gave railends of about 365 Brinell on rails running about 275 Brinell. Heating the heads of the rails at the joint by a flame at the surface, checking the temperature by a pyrometer and either letting the cold metal beneath act as a quench, or quenching by a water spray so regulated in amount that the heat retained below the surface soaks back up to give a draw is also done upon rails in place.[13] There is danger of cracking when the end is built up by welding and the possibility of spalling when the end of the cold rail is heated for quenching in place.

Methods for Combatting End Batter

Bethlehem[18] has developed two methods for combatting end batter. One is a rail, ingeniously cut hot at the mill with the base cut square, as usual, so that the rails will not wedge together, but with the head cut at a 45-deg. angle to provide a lapped, mitred joint so that the wheel is supported in its passage from one rail to another, and no transverse gap exists at which the wheel may drop to batter the corners as in square end rail. This is stated to reduce end batter by 50 to 75 per cent.

A further refinement is the heat treatment of the ends of the mitred rails, carried out while the rail is hot to minimize the danger of spalling. The process can, of course, be applied to square end rails as well. In the hardening operation a water jet, timed by an electrical control, quenches the rail end, the heat of the rail body in turn drawing the head back. More certain control is claimed for this than when a heating and quenching is carried out on a cold rail.

The hot rails, after hardening the ends, can be put through the slow cooling process so as to take precautions against both end batter and shatter cracks. End hardening of rails is also carried on by several other steel mills, and some railroads are end-hardening rails in the field.

Pouring Liquid Steel, Produced by the Thermit Reaction, Into Molds to Provide Weld Metal for the Weld in the Lower Part of the Rails and to Bring the Rail Heads to Proper Heat for a Pressure Butt Weld. (Courtesy Metal & Thermit Corp., New York.).

Hardening the Entire Rail

One may ask why only the rail ends should be hardened. Why not heat-treat the whole rail and thus minimize wear all over, as well as at the ends? The reason why the answer to this question comes slowly is because the shape of a rail makes it a peculiarly mean object to quench without distortion. The Sandberg's in England have advocated a quenching process, using finely atomized water—a so-called "Scotch mist" —followed by slow cooling and seem to be getting away with it to some extent at least, since over 100,000 tons of rails have been so treated in Europe.

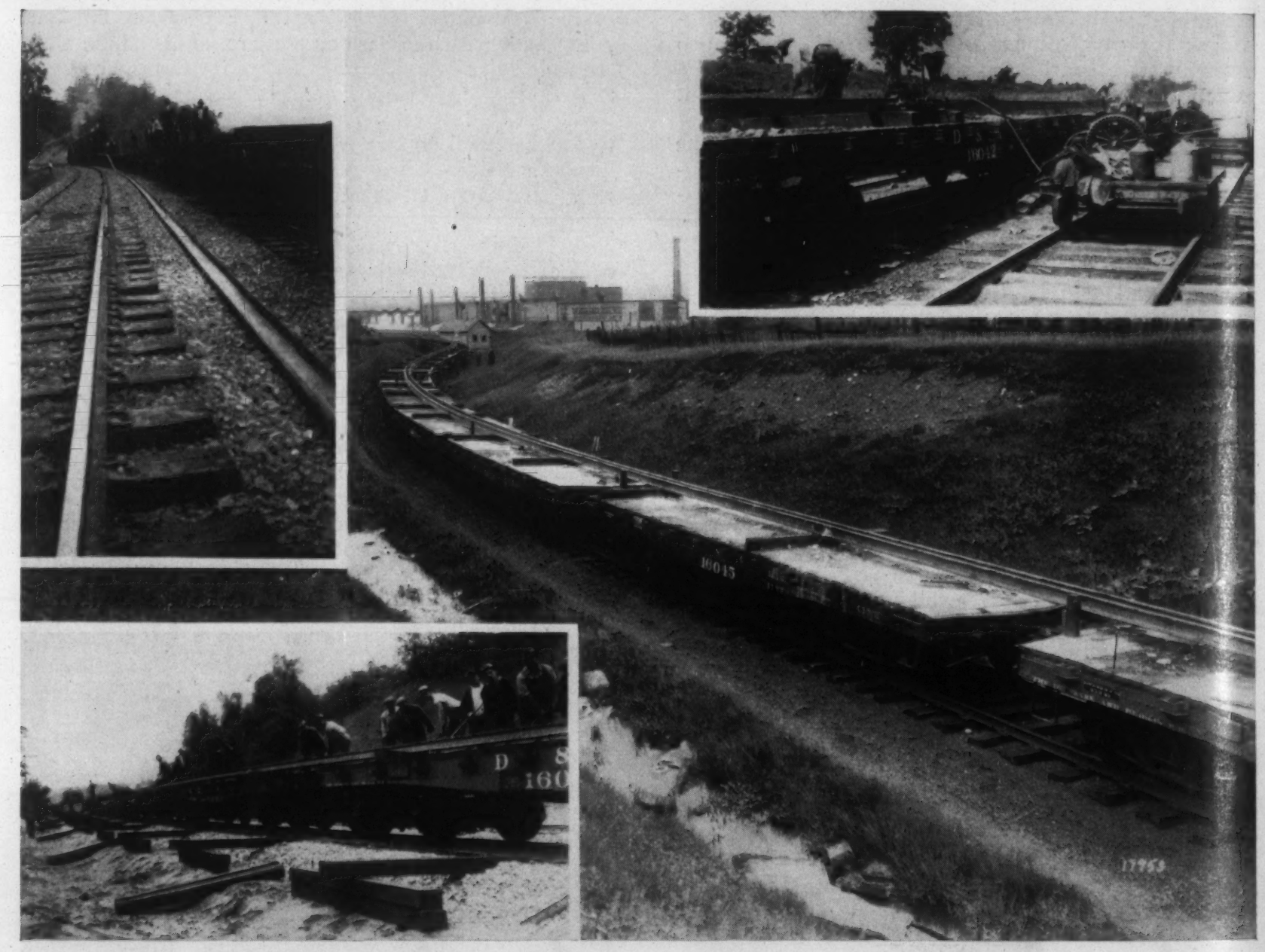
Kenney of Bethlehem has long worked on a process[14] for hardening the whole rail which takes the hot rail, dunks it into water for a limited period and very carefully controlled, normally about 30 seconds, then at once putting it into an equalizing furnace held below the critical temperature, say at 1000 deg. so that internal strains are not set up by too rapid cooling, then straightening hot if necessary, and then preferably slow cooling by the regular procedure for avoidance of shatter cracks.

It is admittedly a difficult matter to secure hardness, straightness and freedom from internal stresses in such a process, but when all this is successfully done the rail, according to tests in progress on five railroads, is reported as showing but 55 per cent as much wear as an untreated rail.

The treatment raises the Brinell from 300 to 360, 85,000 to 125,000 lbs. per sq. in., while leaving the elongation and reduction of area unaffected. The Izod impact figure is raised from 2 up to 7 ft. lbs. and set under the first blow in the drop test is reduced from 0.85 to 0.55 in. The rails so treated are not quite as hard as the ends of the locally heat-treated rails which are brought to around 400 Brinell.

Other Special Treatments

Goodaire[15] discusses the oil quenching and tempering of short rail lengths and special cross-over assemblies. Ordinary rail steel is used, that which has originally been slow cooled to avoid shatter cracks, being



The Long Rails at Schenectady, on the Delaware & Hudson, Were Welded into 700 Ft. and 1400 Ft. Lengths on Top of Flat Cars in a Yard Three Miles Away, Then Hauled to the Site of Installation, Barred Off the Cars, and Placed in the Track. (Courtesy Metal & Thermit Corp., New York.

the tensile from 140,000 to 180,000 and the yield from preferred. The properties of the rails, bodily quenched in oil and then tempered, are about the same as to hardness, tensile and yield strength as those stated for the rails treated by the Kenney process. However, a slight improvement in elongation and a marked improvement[16] in reduction of area is claimed for the oil-quenched material.

Brunner[16] describes the Illinois Steel Co.'s method of "normalizing" or more correctly air-quenching the rail head. The rail is allowed to cool in air till the outside is slightly below the critical temperature, then is reheated to above the critical in order to get temperature equalization throughout the mass. The head only is then chilled by an air blast. By this method the head is brought up to about 360 Brinell.

It is too early to draw conclusions as to how the various heat-treated rails are going to work out on a technical and economic basis in this country, but at any rate the rail metallurgists are not asleep at the switch, they are following up the various avenues leading to the production of a safer and an easier-riding track.

The citation above of an Izod impact figure of only 2 ft. lbs., plus the observation that a poorly supported rail or one over which a flat wheel is running may have to resist a type of impact in service, plus the

Close-Up View of Mitred Rail.

knowledge that carbon steels as a class show a great falling off of impact resistance at low temperatures[17], makes one wonder what might happen to a rail in a cold winter in Canada or the northern states. There seems to be more than a suspicion that rail failures are more prevalent in very cold weather. Whether this is due to impact resistance, having fallen almost to nothing, to contraction stresses due to drop in temperature, or to the frozen road bed failing to absorb energy properly, or to some combination, is not yet clear.

Wishart[6] of the Railways-Rail Mills-University of Illinois Joint Investigation is carrying on low-temperature tests, using the "cold room" at Wright Field. So the problem of dividing the responsibility for cold-weather failures between embrittlement of rail steel and track conditions is being studied.

General Remarks

It may seem that the rate of solution of the metallurgical and engineering problems connected with rails is slow. Nevertheless it is a field in which there is no real answer short of service, for simulated service testing would be horribly expensive if it is really to simulate, and people properly want to feel pretty sure that an experimental rail is not going to fail suddenly before they put it in a main track under passenger trains. It takes years for reliable observations as to the useful life of a rail in service. Reliable data acmulate but slowly.

In such a situation it is not as bad a record as it might seem to have 25 years elapse between the first transverse fissure failure and the widespread commercial availability of rails not prone to such failures. Indeed it is only about a decade since the railroads and the rail mills really quit blaming each other and trying to shift the burden, and got down to pulling together to find what the troubles were really due to, and to do something about it. Since that spirit is bringing results helpful to both, it will doubtless continue and further progress should be more rapid.

From the point of view of the metallurgist the most needed bit of information is what is really the source of the trouble in the one heat out of 50 that won't stand ordinary cooling rates without shatter cracks.

This article concerns primarily the metallurgy of rail steel. However, the extensive service records of the American Railway Engineering Association and the field tests of the Joint Investigation indicate that fissures in rails may be greatly reduced in number by better maintenance of track and of rolling stock.

If the metallurgists, the maintenance men and the engineers who design rolling stock and road beds all keep their coats off and stick to their tasks—as they will do if the railroad and the steel executives continue to cooperate—the fissure menace should be removed long before another quarter century ends.

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Gas Fired Continuous Carburizing Furnace Showing Pots Coming Out at the Discharge End.

Automatic Machines for Carburizing

By J. B. NEALEY

American Gas Association

IN THE LARGER PLANTS where mass production is the order of the day, the heat-treating processes must be made continuous and automatic. A flexible fuel that lends itself to easy control must be chosen; continuous conveyor systems must be provided and furnaces must be designed so as to correlate several varying factors. Occasionally heating machines are incorporated in the production line and the speed and capacity synchronized to those of the other tools in the line. More frequently, however, a separate heat-treating division is set up and all or part of the furnaces are grouped here.

Both of these methods are employed by General Motors Corp. and the plant of the Buick Motor Co., Flint, Mich., is no exception. Many thousands of cubic feet of gas are used in these processes. One heat treatment, that of case hardening, is accomplished in three different ways—cyaniding, pack carburizing and gas carburizing. The first is a difficult process to mechanize but this has been successfully accomplished for heating transmission gears. This is done by the use of a preheat furnace, a series of gas heated cyanide pots and a conveyor with a combination of horizontal and vertical movements and known as the "jack rabbit" type. There are several of these units, the larger consisting of a preheat furnace, four cyanide pots and three tanks which quench, wash and rinse.

These are arranged in a single row with two closed loop traveling chains above with rods between. There are two parallel series of sprockets for these chains to ride on, each sprocket bridging the space between two pots or tanks. The gears are hung on tools suspended from the rods between the chains. Each cyanide pots sets in an individual furnace of brick and refractory construction with a steel case. These furnaces are 4 x 4 x 6 ft. long and each is heated with two gas burners firing into one end.

Temperature Controls Automatic

Automatic temperature controls are provided which actuate solenoid equipped valves in the air lines to the burners. Pressure air is employed to inspirate gas in the correct proportion for complete combustion. As the valves are of the on and off type, the gas burners are served with pilot lights. The first furnace in line is for preheating and a time cycle of 6 min. is used, that is, the gears remain in each pot for this time period. The three pot units employ a 9 min. cycle. These cycles are controlled by a time clock and light system, an operator simply pushing a button upon the flashing of the lights.

The gears are S.A.E. 3145 steel with a carbon range of 0.43 to 0.48 per cent. They are heated by steps to 1500 deg. F. and are in the cyanide for a total of 24 min. In this time they acquire a case depth of 0.002 in. which depth has been found to provide all the wear resistance necessary. A heavier cyanide case is thought to be detrimental to fatigue as well as to shock resistance when the core hardness is C-50 or more. Distortion is reduced to a minimum by quenching in standing oil, so the oil flow is auto-

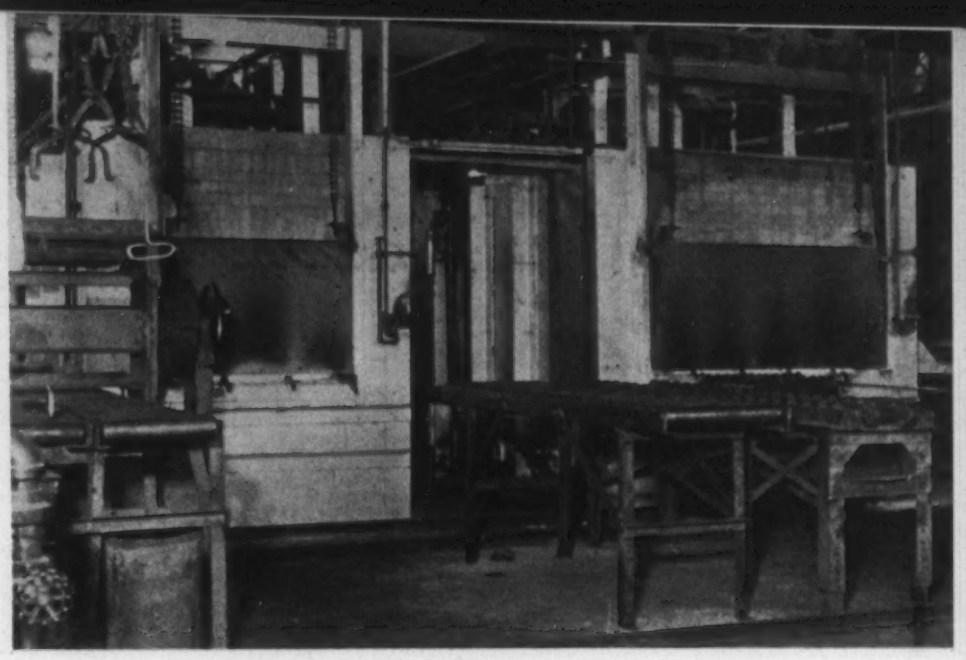
matically stopped for 1½ min. at the time of immersion and the oil pump automatically resumes with the starting of the cycles.

The cyanide pots are carried at 1325, 1500, 1500 and 1325 deg. F. respectively while the preheat furnace is heated by waste heat from the others to 400 to 600 deg. F. From this it will be evident that the quenching temperature is just above the Ar_3 point of the steel. The gears are then drawn at 450 deg. F. in another furnace. The four pot cyanide units handle 800 lbs. of gears per hour and the draw unit handles 1200 lbs. of gears per hour. Recording pyrometers for all pots, as well as for some of the other furnaces here, are mounted in a central control room. Telltale lights are also provided in some cases. There are a number of single cyanide pots, similar to those described, which are used for miscellaneous work.

Carburizing With Gas Furnaces

Pusher type furnaces are used for pack carburizing and two are 35 ft. long and 8 ft. high. One of these is 8 ft. wide and has four double tracks while the other is 6 ft. wide with two double tracks. These are outside dimensions. The tracks are equipped with rollers. These are three-zone furnaces with nine gas burners on each side, underfiring the hearths. An automatic temperature control and recording pyrometer is supplied for each zone. The gears are packed in pots with carburizing material and the pots ride through the furnaces on trays. Roller tables are provided at the front and rear of the furnaces and a gravity roller conveyor along one side for the return of the empty pots. The pots are handled by hoists suspended from overhead tracks. The work is quenched in oil.

A quenching machine is used to minimize distortion and consists of upper and lower dies between which the gears are held. One die is perforated and the other segmented, the segments bearing on both the web and the teeth to equalize the pressure. Oil is forced through and around the work at 60 lbs. pressure.

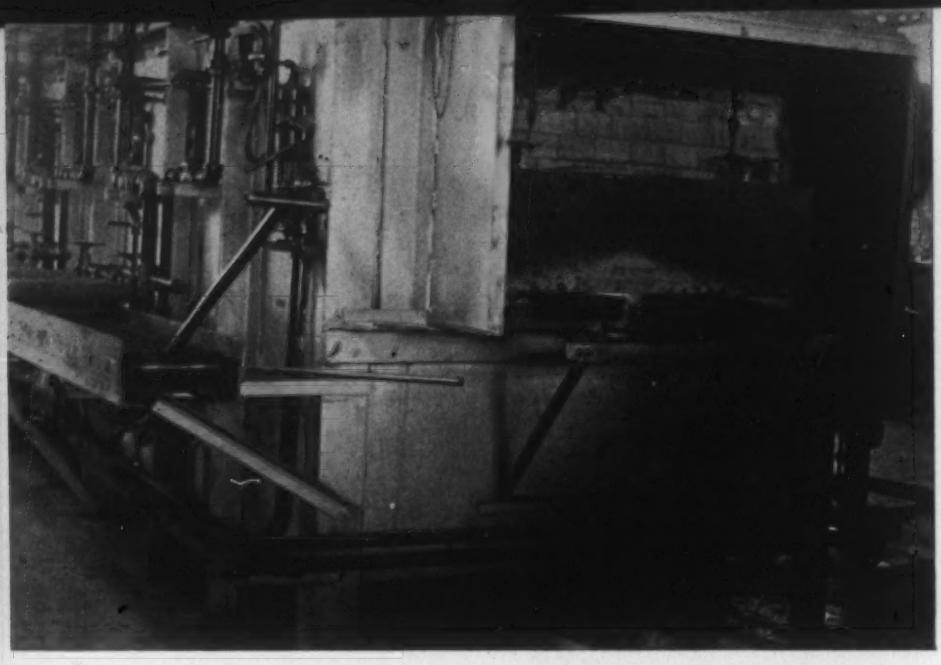


Two Continuous Carburizing Furnaces, Gas Fired, Both of the Pusher Type.

Another pusher furnace, 24 ft. long and 6 ft. wide, is used for hardening spline shafts. These shafts are packed in steel tubes 14 in. long and 1½ in. in diam. and the tubes ride through the furnace on trays. A special quenching machine consists of a fixture holding 27 shafts vertically. This lowers them into the oil leaving one end protruding as it is necessary to keep this part soft.

The gas carburizing furnace is one of the most recent and is of the continuous full muffle type equipped with a mechanical pusher. One of the newer type prepared atmosphere units re-forms and otherwise prepares city gas which is forced through the muffle to act as the carburizing medium. The furnace is 22 ft. long, brick refractory and steel construction and is heated by a number of gas burners on each side. The furnace is zoned by the use of three automatic temperature controls. The oval shaped muffle is 3 ft. wide and 1½ ft. high and contains two tracks on which ride skeleton trays loaded with gears. The furnace is closed at the discharge end and the work is lowered through an opening in the bottom near this end by means of an elevator conveyor into the

Continuous Hardening Furnace Showing Tubes in Which Spline Shafts are Packed for Heating.



Another View of Gas Fired Hardening Furnace.

quench below. An oil seal between the muffle and quench preserves the muffle atmosphere.

The furnace temperature is 1500 deg. F. in all three zones and a case slightly hyper-eutectoid with the excess cementite in spheroidal form is obtained. A case depth of 0.006 in. results which is 0.004 in. deeper than that of the cyanided gears and much tougher. As both the heating up time and total period (88 min.) in the furnace is longer than in cyaniding, distortion is less. The capacity of this furnace is 1200 lbs. per hr.

Draw Furnaces

All of the above described work is drawn at approximately 450 deg. F. in continuous gas fired furnaces. These furnaces are vertical, with a tray type chain conveyor, and vary only in cooling arrangement for the drawn stock. The gear draws, liquid cooling, are 8 ft. wide, 6 ft. deep, and 20 ft. high overall dimensions. These furnaces, of frame construction, and lined with insulating brick, are open for the first 6 ft. on one side for charging and discharging. Just above this opening and extending across the center of the oven are two refractory lined combustion tunnels, with open slots across the top.

Two gas burners fire into these tunnels from the end, and the hot products of combustion receive uniform distribution along the oven width by means of the slot. A vertical sheet steel baffle directs the heated gases counter flow to the travel of the stock, the gases leaving at the bottom, against the cold stock entering.

Temperatures are automatically controlled. A tank filled with a soluble oil and soda ash solution is located at the bottom, and is set at the proper level for the work to pass through, just prior to coming up to the discharge position.

The spline shaft draw is similar in construction, except that the conveyor is extended horizontally as it leaves the furnace proper, to allow the heated shafts to air cool on the conveyor, and also to facilitate the loading by the shaft straightening operators.

Heat Treatment Varied

Stabilizer arm shafts, propeller shaft tube couplings, etc., are of S.A.E. 1045 steel. The former are heated at 1500 deg. F. for ¾ hr., quenched in water and drawn at 900 deg. F. for 2 hrs., which results in a Brinell hardness of 302 to 341. The latter are heated at 1550 deg. F. for 3 hrs., and drawing it at 1000 deg. F. for 2 hrs., leaves it at 255 to 302. Side gears are of both S.A.E. 1115 and 3115 steel and are carburized at 1700 deg. F. for 10 hrs., for a 0.040 to 0.050 case (water quench). The 3115 side gears, however, are transferred directly from the carburizing box to cyanide at 1475 deg. F., held in the cyanide for about one minute, and then quenched in oil. All rear axle drive pinions and ring gears are of 4615 steel and are carburized at 1700 deg. to a 0.040 to 0.050 case for 10 hrs. and quenched direct in oil. Axle shaft spacers are given a similar treatment with the addition of a brine quench from 1430 followed by a 375 deg. F. draw. There are several other gas fired furnaces in this plant, some in the heat-treating division and some in the production lines but they do not differ sufficiently from those mentioned to warrant a separate description.

Continuous Cyaniding Installation for Heat Treating Ring Gears. The furnaces are gas fired and have the "Jack Rabbitt" type of conveyor.

Hardening Razor Blade Steel

By a New Process

BY ALBERT R. STARGARDTER

Chief Metallurgist, Gillette Safety Razor Co., Boston, Mass.

SINCE early attempts at magnetic inspection and control of the hardening process were surrounded with considerable mysticism and seldom acted, in other's hands, as their proponents claimed, a case of commercial utilization of magnetic control is at least interesting. Of course, such an oufit could be used for its advertising value as much as for its technical worth, and this particular outfit is featured in the general advertising of the blades.

The metallurgist wonders what percentage rejections or what hardness variations were met before and after the installation of the control. Obviously, this method only controls after a blade outside the desired limit of permeability has been produced, and an unstated time must elapse and a number of blades must be produced before the temperature of the hardening furnace can be raised or lowered. Information as to whether these defective blades are automatically marked for rejection at this point or whether another inspection is required to reject these would be of interest.

Without question, the metallurgical staff has all this information but, on request to the author to add it, we were informed that any more detailed description of the process would be against company policy. This leaves the description somewhat incomplete and unsatisfactory from the metallurgical point of view. However, the bare fact that a firm has decided it to be worth while to spend money to vary quenching temperature just as rapidly as possible during operation of a continuous furnace in order to get greater uniformity in the quenched product, instead of operating at a fixed temperature, is worth putting on record. U. S. Pat. 2,041,029, issued since this article was received, describes a control method of this type in some detail.

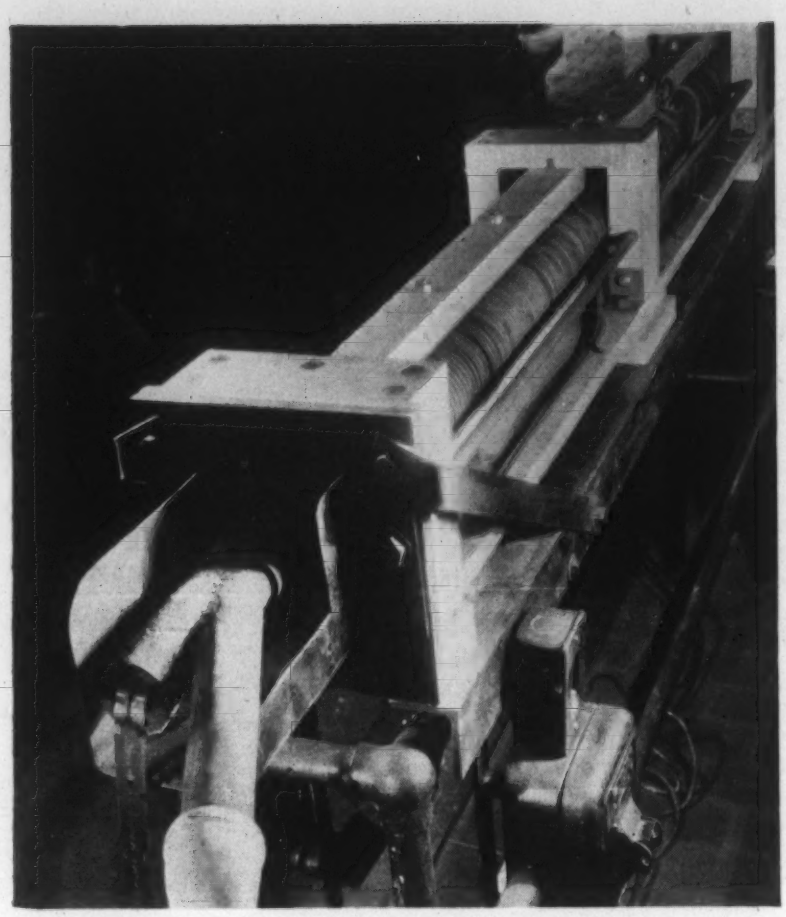
The mere fact that the advertising department seizes the opportunity to discuss the new features of the set-up, in the vague and mystical terms common in general advertising, need not condemn the process in the eyes of the technician, though his appreciation of the process would be enhanced were the description less sketchy.—H. W. G.

CONSTANT RESEARCH has yielded the conclusion that, in order to obtain perfection in razor blade production, the steel delivered to the blade edging machines must be absolutely uniform in composition, microstructure and hardness.

Early Condirions in Hardening Razor Strip

As early as 1925 a fair degree of uniformity in hardening razor strip (analyzing 1.20% carbon and 0.20% chromium) had been obtained. The production method in general use consisted in passing the annealed strip,

General View of Gillette Hardening Plant for Razor Blade Steel Showing 18 High Frequency Furnaces in Operation. At the left hand of the operator in the foreground is shown the electromagnetic hardening control box which is an essential item for each furnace.



Close-Up of Furnace with Cover Removed Showing Steel Entering the Nichrome Muffle Through an Adapter and the Construction of the Induction Coil of Copper Tubing.

which had been perforated with the required blade outline and perforations, through long heating furnaces of the muffle type, usually gas or electrically heated, and, after quenching the strip between water-cooled blocks, drawing it to the desired temper. After passing through the tempering plates the strip was then coiled and, after polishing and printing, was ready for the edging process. All existing heating equipment was pyrometrically controlled; that is, maintained as accurately as possible at a given optimum temperature.

General improvement in the field of strip steel hardening and tempering yielded better furnaces with improved thermal efficiency and better pyrometric equipment. This tendency must have been, and really was, brought about by a definite point of view. The goal in sight was equipment which could be operated perpetually and at a certain temperature with practically no variation.

The Gillette company availed itself of the improved equipment when it was offered, but at the same time realized that nothing was being developed to produce absolute uniformity in hardened strip steel and for this reason carried on its own development work. The theory which guided us along our own path of development, was this: Uniformly hardened strip cannot be obtained by quenching from a uniform temperature. It must be remembered that our steel is delivered to the furnaces in 35-lb. coils, and that, while the general quality of our steel supply, judged by ordinary standards, is as high as can be attained today, it is not yet completely uniform, and that slight variations in structure occur not only from coil to coil but very often within the coil itself. The slight variations in the steel strip before hardening are substantially only variations in the size and distribution of the spheroidized cementite particles; in other words in the amount and form of carbide out of solution.

Application of Magnetic Control

From our research work we ascertained that these conditions in the strip before hardening could best be ascertained in the hardened strip by magnetic testing. This was due to the fact that the varying strains occurring in annealed strip are entirely removed in the hardening operation. We found that after hardening, the permeability of the hardened strip was inversely proportional to the amount of carbide in solid solution. The testing equipment consisted of balanced, step-down transformers with bucked secondaries in which the steel test piece is tested against a standard piece of known characteristics. Registration is obtained on an oscillograph or by means of an A. C. galvanometer. We then realized that, if we would secure a set of control instruments actuated by an alternating current galvanometer, we would then be able to secure the uniformity we desired, provided we could secure a hardening furnace affording very rapid temperature changes.

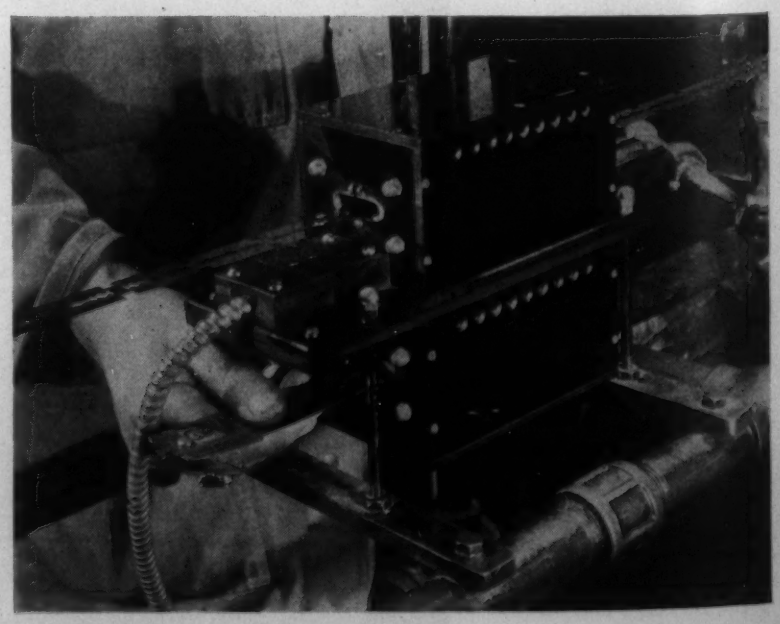
In other words, we would run each hardened and quenched strip through a test coil whereby it would be constantly maintained under electrical comparison with a hardened standard piece having the desired hardened microstructure. The output of the test coils would actuate an A.C. galvanometer so constructed as to be the operating element for a control instrument which would so make and break furnace heating contacts as to secure in the hardened product the precise amount of heating necessary to exactly duplicate the magnetic characteristics corresponding to the structure of the standard piece having the desired metallurgical characteristics.

We had now reached the stage where we were no longer satisfied with the constant temperature thermal control obtainable on the market, but decided to build our own control system and so attain our own self-imposed high standards of accuracy. After a great deal of experimenting, the necessary magnetic control assembly was finally perfected. This magnetic control system was successfully utilized on a small-scale hardening furnace after more than two years' research. We were then ready for the second phase of our problem—the completely flexible furnace.

A High Frequency Furnace Developed

This furnace was not available and had to be developed for our needs. We submitted the problem to a reputable company and after a period of experimentation they delivered to us—in the fall of 1931—the first

The Electromagnetic Control Transformers. The steel proceeding through the upper box has just left the quench and is under electromagnetic comparison with the lower or standard piece.



high frequency hardening furnace ever built. It was successful from the start and proved to be the forerunner of our present hardening plant consisting of high frequency hardening furnaces, each electromagnetically controlled solely by the emerging quenched strip.

Our present system, as outlined above, consists of a battery of 18 high frequency furnaces. These furnaces, are energized by two high frequency motor generator converter sets, each set being operated by a 3-phase, 150-h.p., 440-volt, 60-cycle motor which turns at a speed of 3600 r.p.m., a 60-kw. single-phase frequency generator, yielding 550-600 volts at a frequency of 4800 cycles with unity power factor. The furnaces are equipped with nichrome muffles through which the steel strip passes. The muffles are surrounded by high frequency copper induction heating coils having about 500 turns and resonated with a suitable condenser in parallel. The copper induction coils are about 1/8 in. inside diameter and in operation are cooled by passing a constant flow of water through them. The nichrome muffles acting as capacitators are inductively heated, and since heating by this method is very rapid and the muffle insulation is very thin, (about 1/2 in.) both heating and cooling rates are extraordinarily high. When the power is off, the cooling is greatly accelerated by the cold water flowing through the induction coil surrounding the muffle.

Each furnace is equipped with two contacts, one for accelerated heating, and the other for holding at a constant heat input. This system is controlled by the above-described electromagentic controller which in turn is actuated by the hardened strip. Any deviation in original microstructure producing a hardened structure with magnetic properties at variance with the controlling standard piece will produce at once a compensating furnace heat change either by closing the accelerated heating circuit or by turning off the current entirely, as the case may be. The furnaces can be heated from room temperature to hardening heat (about 1450 deg. F. in about 35 min. and can therefore be economically operated.

The above-described plant has been in operation for over three years and has made possible a constant supply of hardened, tempered razor strip steel possessing a degree of uniformity unobtainable by any other means.

The results of microscopic examination of the razor blade steel during various steps in the treatment described are revealed in the accompanying photomicrographs.

Some of the 18 Electromagnetic Controllers. There is one for each furnace and the impulses received from the control transformers, shown in Fig. 3, are utilized instantly by these controllers to make and break the furnace control contacts as needed.

Fig. A shows the correct microstructure of a Gillette razor blade edge. The part played by the carbides in the formation of the edge may be clearly seen. This edge is durable. The incorrect microstructure of the edge of a Gillette blade is shown by Fig. B. Here the carbides are too large in size, are not uniform and are not evenly distributed. Such an edge will not stand up.

The structure of a domestic razor strip steel in the unhardened condition is shown by Figs. 1 and 2, while Figs. 3, 4 and 5 represent the structure of Swedish razor blade strip steel. These show the extreme variations encountered in such material when unhardened.

The structure of some faulty strip, which would be rejected as unfit for use, is shown by Fig. 6. The blade edge of Fig. B was made from this steel.

A separate standard hardening control piece is used for steel from each supplier so that the standard piece has the same "prenatal" history as the material it is controlling.

The microstructure of the steel shown by Figs. 3, 4 and 5 after hardening by magnetic control is revealed by Figs. 3-H, 4-H and 5-H respectively. Steel No. 4 had exactly the same structure both before and after hardening as the standard control piece. The hardening temperatures, automatically selected by the magnetic control system, were measured at a distance

Fig. A

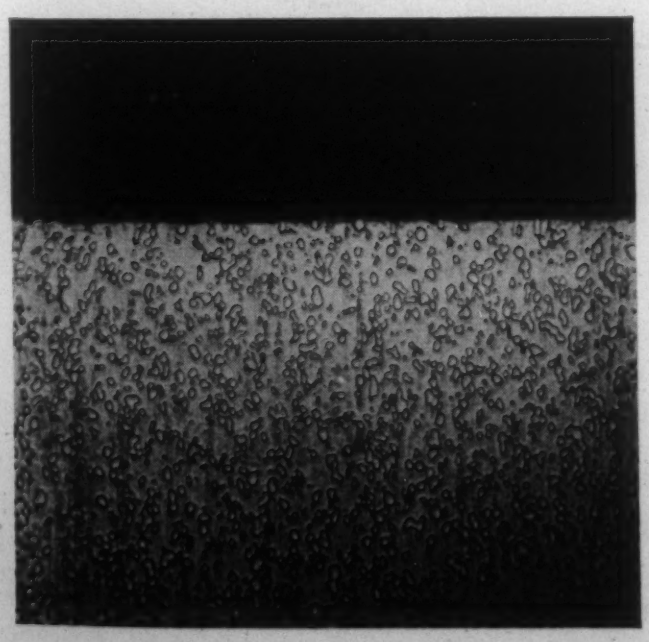


Fig. B

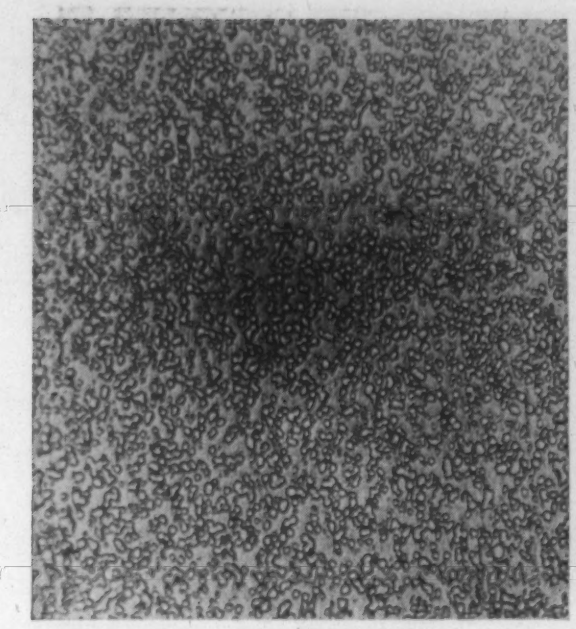


Fig. 1

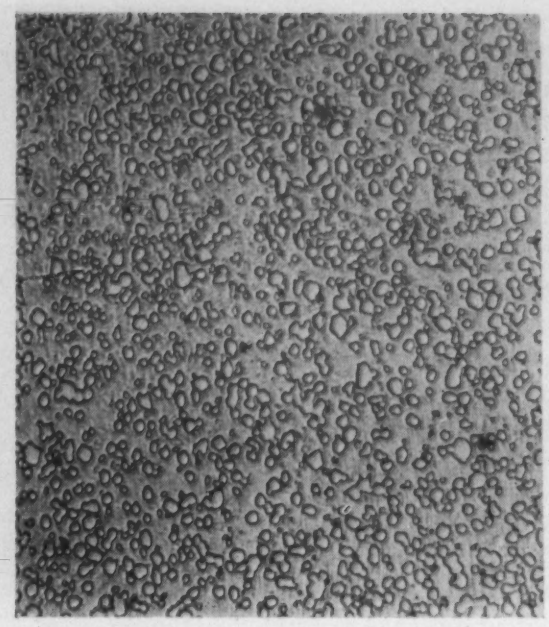


Fig. 2

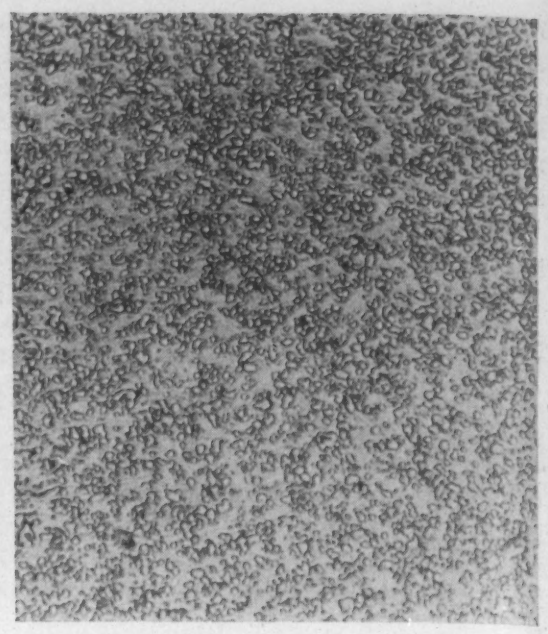


Fig. 3

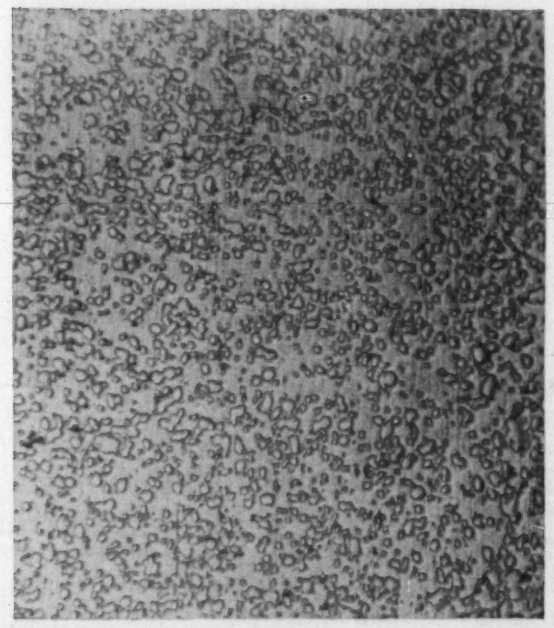


Fig. 4

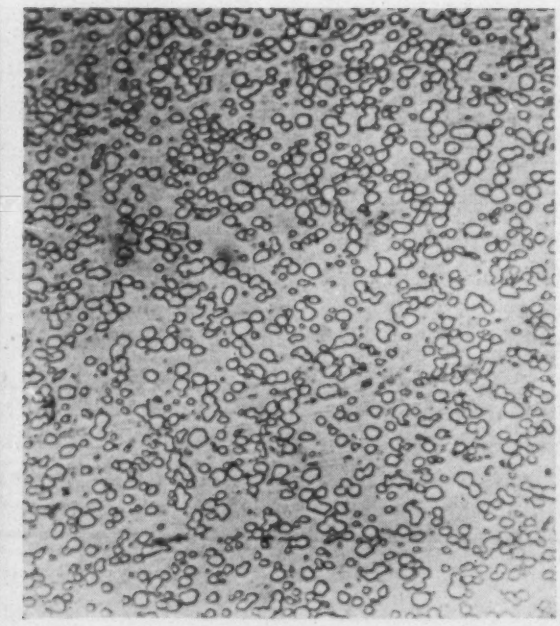


Fig. 5

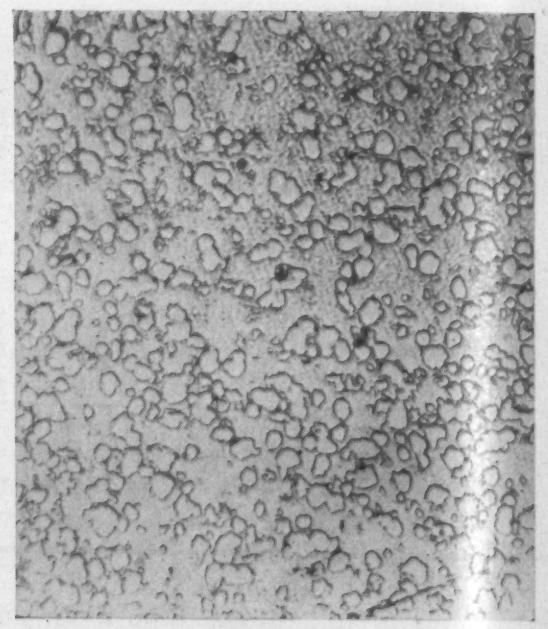


Fig. 6

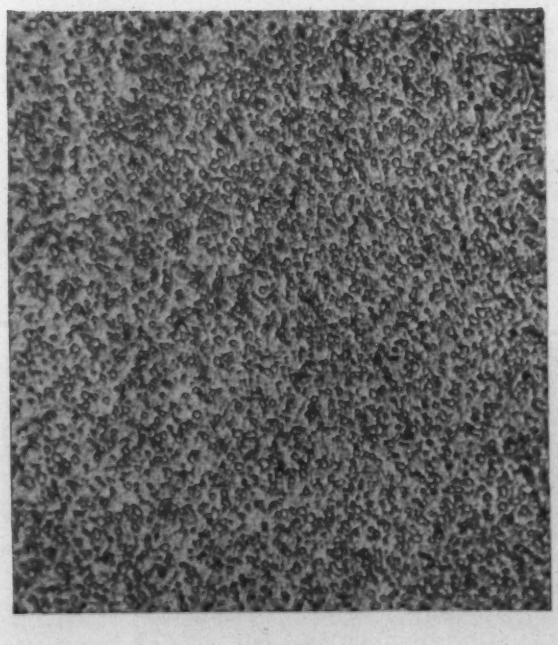


Fig. 3H

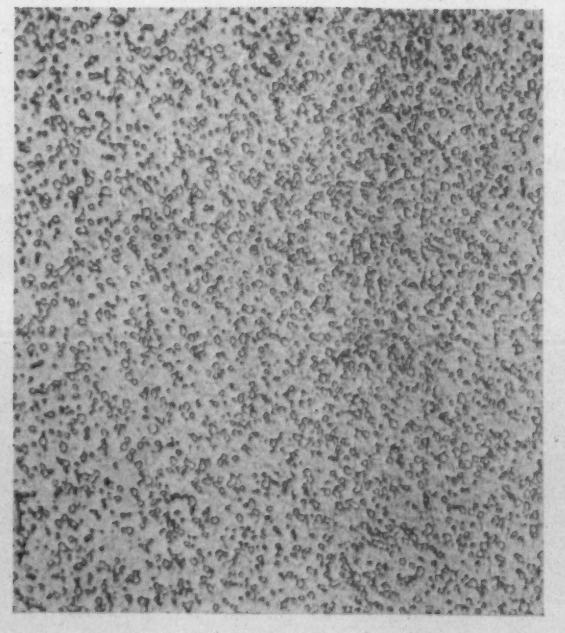


Fig. 4H

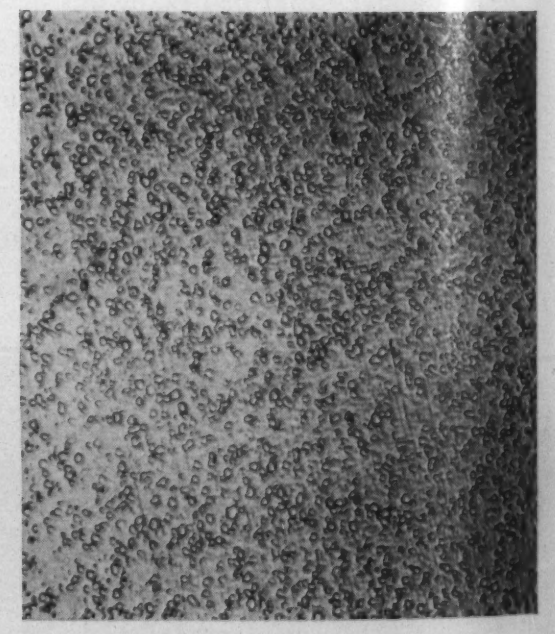


Fig. 5H

of 5 in. from the exit end of the furnace muffle. They were reported as follows:

Steel	*Deg. F.*
No. 3	1440
No. 4	1458
No. 5	1481

These steels represent the extreme differences in structure which will pass our inspection system.

In the same way less pronounced differences in structure are being constantly compensated for by our electromagnetic control system, so that our final hardened product is far more uniform than could be obtained from constant thermo-control of the conventional type.

Copper Castings Alloyed With Be and Ti

Hardness and Conductivity After Heat Treatment

By G. F. COMSTOCK

Metallurgist, Titanium Alloy Mfg. Co., Niagara Falls, N. Y.

THIS PAPER GIVES the results of Rockwell hardness tests and electrical conductivity measurements on copper castings containing up to 2.7 per cent beryllium and up to 1.2 per cent titanium, heat treated in various ways with the object of developing the best combination of hardness and conductivity. Larger percentages of these alloying elements were not tried, both on account of the expense involved, and also because of the unfavorable effect on the electrical conductivity.

The beryllium in some of the heats was obtained from 12.5 per cent beryllium copper, and in others from 2.5 per cent alloy or from remelted scrap. The charges were melted in Dixon clay-bonded graphite crucibles heated by gas, and no trouble was encountered in securing perfect recovery of the beryllium added when charcoal was used as a cover. The copper was melted first, and then the beryllium alloy dissolved in it. When glass was used as a cover, there was a serious loss of beryllium and an increase in the silicon content of the melt.

The titanium used was our own "TAM" metallic titanium in fine particles (about ½ in. to 20 mesh) and was added by means of a small graphite phosphorizer after the melt had been superheated, deoxidized, and freed from the glass or charcoal cover. A glass cover was preferred when beryllium was not used. The melts were deoxidized with 1 per cent of a calcium-silicon alloy known as Alpro No. 11. Silicon contents were obtained from 15 per cent silicon-copper, added just before the titanium. The titanium additions were calculated on the basis of 80 per cent recovery, but actual recoveries were generally higher. The heats were usually superheated to 2450 or 2500 deg. F., as measured with an optical pyrometer on the inside of the crucible, before adding the phosphorizer containing the titanium, and they were poured about 5 or 10 min. after that addition.

The castings were poured in dry sand cores. They were rods 16 in. long and ⅝ in. wide, gated near one end and with the riser at the gate, the sprue being about 6 in. away. The lower half of the bar was round, but the upper half was pointed or triangular in section to provide space for dross to lodge so that it would be removed in machining. For hardness tests these bars were cut up into sections about ¼ in. thick, but for conductivity tests they were machined to ½ in. diameter for a length of 14½ in.

The heat treatments were carried out in an electric muffle furnace with automatic temperature control. The furnace was always brought up to temperature before inserting the specimens, and the furnace was large enough in comparison with the specimen load so that there was little delay in heating up the specimens. The hardness tests were made with the standard Rockwell machine, using the E scale (⅛ in. diameter ball and 100 kgm. load), and about ten determinations were made on each specimen, the average being reported after discarding one or two abnormally low or high results. A reading of 70 on the Rockwell E scale corresponds to about 65 Brinell; 100 is equivalent to about 125 Brinell; and 115 to about 250 Brinell.

The conductivity tests were made with a Kohlrausch bridge arranged with standard resistances in a special assembly designed for cast copper rods of very low resistance. This apparatus was checked occasionally with a standard bar which was tested twice by the Bureau of Standards, and it gave results accurate within 0.5 per cent. The usual correction was always made for the temperature of the specimen when tested, and the results are reported as conductivity by mass (or per metergram) in per cent of the standard value for pure copper.

Table 1.—Hardness and Conductivity of Two Copper Alloy Castings after Various Treatments.

Alloy Content, per cent	Heat Treatment	Rockwell E Hardness	Electrical Conductivity, per cent
2.04 Be	None. As cast	90.0	22.0
	Quenched from 1475°F.	74.5	18.8
	Tempered 5 hrs. at 700°F.	118.0	32.8
0.87 Ti 0.35 Si	None. As cast	80.0	27.3
	Quenched from 1650°F.	49.0	26.9
	Tempered 48 hrs. at 850 to 950°F.	87.0	46.5

In copper alloys containing either beryllium or titanium, a compound is held in solution at temperatures around 1600 deg. F., and precipitates from solution at lower temperatures. This precipitation may be prevented by rapid cooling from the solution tem-

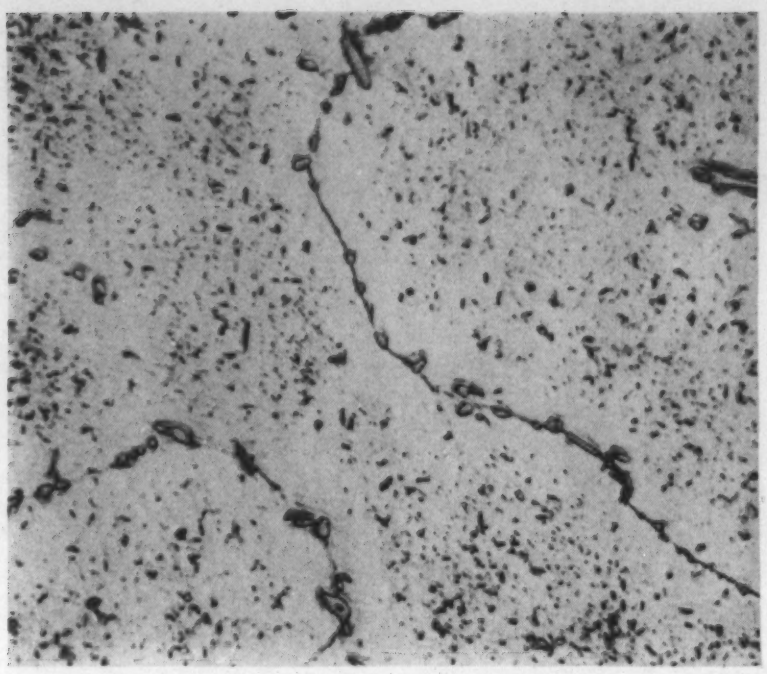


Fig. 1. Copper Casting Treated with Ti and Si and Heat Treated. Quenched in water after 2 hrs. at 1650 deg. F. Conductivity about 20%. Rockwell 60 E. Brinell about 58. Ti 0.83 and Si 0.30%. Etched with ammonia and hydrogen peroxide. Magnification 500 diameters.

perature, and then on reheating to a lower temperature for a sufficient period of time the precipitate separates into very fine particles and causes hardening. The electrical conductivity also is improved by the release of the compound from solid solution. The effects of these changes in a beryllium alloy and in a titanium alloy are indicated by the data presented in Table 1.

Some photomicrographs illustrating the precipitation of a compound in the titanium alloy are presented with this report. It is evident from them that there is some compound which is by no means completely dissolved in the quenched alloy, but nevertheless an additional precipitate is plainly seen to have formed in the tempered alloy.

The hardness and conductivity obtainable in copper castings containing titanium but no beryllium have been found to depend largely on the silicon content which is present with the titanium. A patent has been applied for on this development, but a summary of our findings along this line is given below so that the results may be compared with those on the beryllium alloys forming the subject of this report.

Castings containing 0.5 to 0.9 per cent titanium and low silicon (0.03 to 0.19 per cent) had Rockwell hardness of about 88 E and 24 to 36 per cent conductivity after quenching from 1650 deg. F. and tempering 24 hours at 850 deg. F. When the silicon content was 0.23 to 0.40 per cent, the Rockwell hardness was about 85 E and the conductivity 42 to 45 per cent after the same heat treatment. These conclusions were drawn from a series of five separate heats for each class of alloy. The tensile properties were about the same for each class, namely 20,000 to 30,000 lbs. per sq. in. yield point with 35,000 to 45,000 lbs. tensile strength, and 7 to 27 per cent elongation. By tempering at about 1050 deg. F. instead of 850 deg., the conductivity was raised to 65 or 70 per cent, but with Rockwell hardness of only 67 to 74 E, and yield point about 17,700 lbs. per sq. in. These values may be compared with the following for pure copper castings of about 85 to 90 per cent conductivity: Yield point 6,000 to 9,000 lbs. per sq. in., tensile strength 17,000 to 20,000 lbs., elongation 40 to 50 per cent, and Rockwell hardness about 35 F.

The temper-hardening properties of titanium-copper

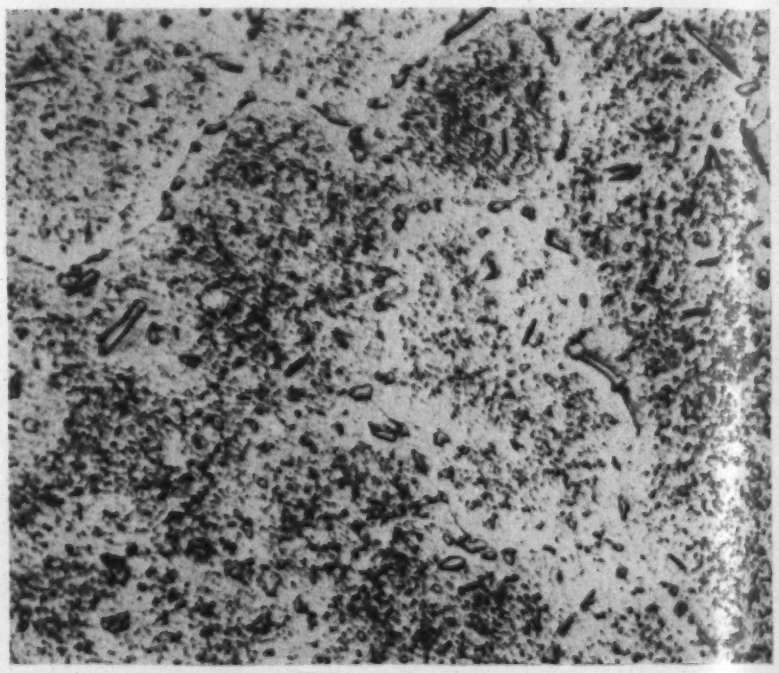


Fig. 3. Copper Casting Treated with Ti and Si and Heat Treated. Quenched from 1650 deg. F., then tempered 24 hrs. at about 1050 deg. F., and slowly cooled in the furnace. Conductivity 62.6%. Rockwell 67 E. Brinnell 65. Yield point 17,700 lbs. per sq. in. Ti 0.90 and Si 0.35%.

Fig. 2. Copper Casting Treated with Ti and Si and Heat Treated. Quenched from 1650 deg. F., then tempered 24 hrs. at 850 deg. F., and air-cooled. Conductivity 41.4%. Rockwell 82 E. Brinnell about 78. Yield point 21,200 lbs., 44,300 lbs. per sq. in., elong. 16.5%, reduction of area 23.2%. Ti 0.83 and Si 0.30%. Etched with ammonia and hydrogen peroxide. Magnification 500 diameters.

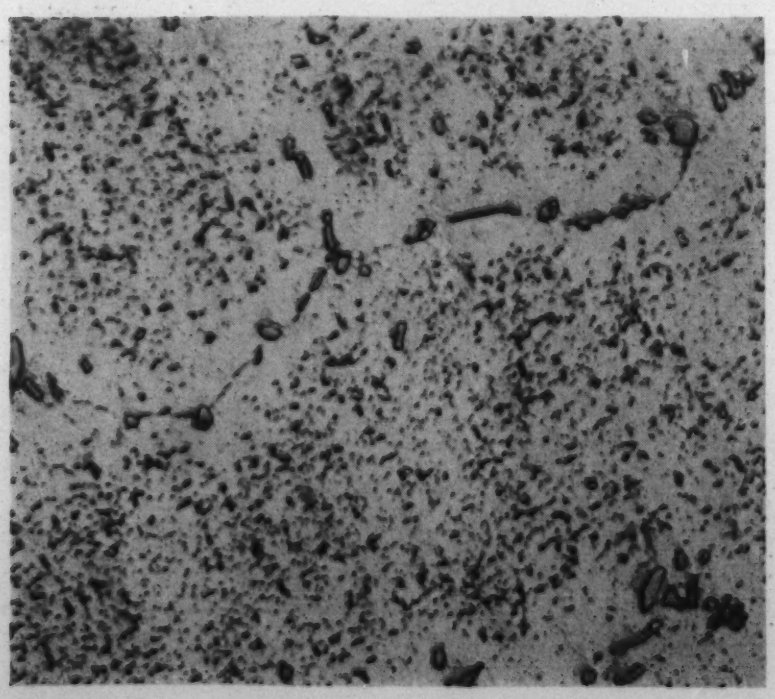


Table 2.—Conductivity and Hardness of Hardened Beryllium Copper Alloys

Heat No.	Chemical Analysis			Heat Treatment Temp., deg. F.		Time of Tempering, hrs.	Electrical Conductivity, per cent	Rockwell E Hardness No.
	Be	Ti	Si	Quench	Temper			
26	2.7	...	...	1475	700	5	35.8	120.0
27	2.04	...	...	1475	700	5	32.8	118.0
28	1.92	...	...	1475	625	14	31.1	122.0
47	1.52	...	...	1550	600	48	36.1	116.5
48	1.53	1.10	0.08	Unsound; not tested but remelted with additional Ti, as heat 50.				
50	1.5?	1.20	0.1?	1550 and 800	600	48	26.4	117.0
49	1.52	0.95	0.31	1550 and 730	600	72	35.0	114.0
58	1.10	...	...	1600	750	72	33.6	89.0
59	1.01	1.15	0.25	1600	750	72	29.0	99.5
44	0.52	...	...	1600	950 and 600	24	39.6	38.0
45	0.35	0.66	0.37	1600	950	24	30.3	80.0
46	0.11	0.51	1.15	1600	950	24	14.8	67.0

alloys with the following additions were also investigated: 2 to 6 per cent cobalt, 2 to 6 per cent nickel, 4 to 7 per cent zinc and 0.8 per cent aluminum. All of these alloys could be hardened by tempering, but those with silicon and zinc were the only alloys which showed as much temper-hardening as the plain titanium copper alloys. The zinc alloys did not show conductivities above 23 per cent after heat treatment,

Table 3.—Rockwell E Hardness after Tempering Quenched Alloys For 12 to 24 Hrs. (Except as Noted).

	Tempering Temperature—Deg. F.										
Alloy—(%)	550	600	650	660	700	730	750	800	850	900	950
E (1.0 Ti)	...	...	75	...	...	...	94	...	104	...	95
LD (0.9 Ti, 0.2 Si)	...	...	73	...	...	...	92	...	91	...	88
47 (1.52 Be)	...	116	...	112	...	110	...	102	...	...	...
49 (1.52 Be, 0.95 Ti, 0.3 Si)	...	104	...	114	...	112	...	108	...	...	...
50 (1.5 Be, 1.2 Ti)	...	112	...	113	...	114	...	112	...	...	...
58 (1.1 Be)	60	73	...	90	...	93.5	...	94.5	...	76	...
59 (1.01 Be, 1.15 Ti, 0.25 Si)	86	90.5	...	95	...	102	...	102	...	96	...
27 (2.0 Be)*	116	119.5	120	...	119.5	...	117	...	...	...	...

* Note: The periods of time at each temperature for alloy 27 were only 3 hrs., and they were cumulative, all the treatments having been made consecutively on the same specimen.

so silicon was the only third alloy addition which was found to be beneficial.

The compositions of the alloys used in the investigation of cast beryllium copper, with and without titanium, are given in Table 2. In this table are also shown the conditions of heat treatment giving maximum hardness, and the hardness and conductivity after that treatment. Titanium was added only to the six heats for which a titanium content is noted. The time of heating before quenching was always 2 hrs.

In these alloys with about 1 per cent or less beryl-

Fig. 4. **Hardness of Quenched and Tempered Alloys and Hardness after Tempering at Constant Temperature.**

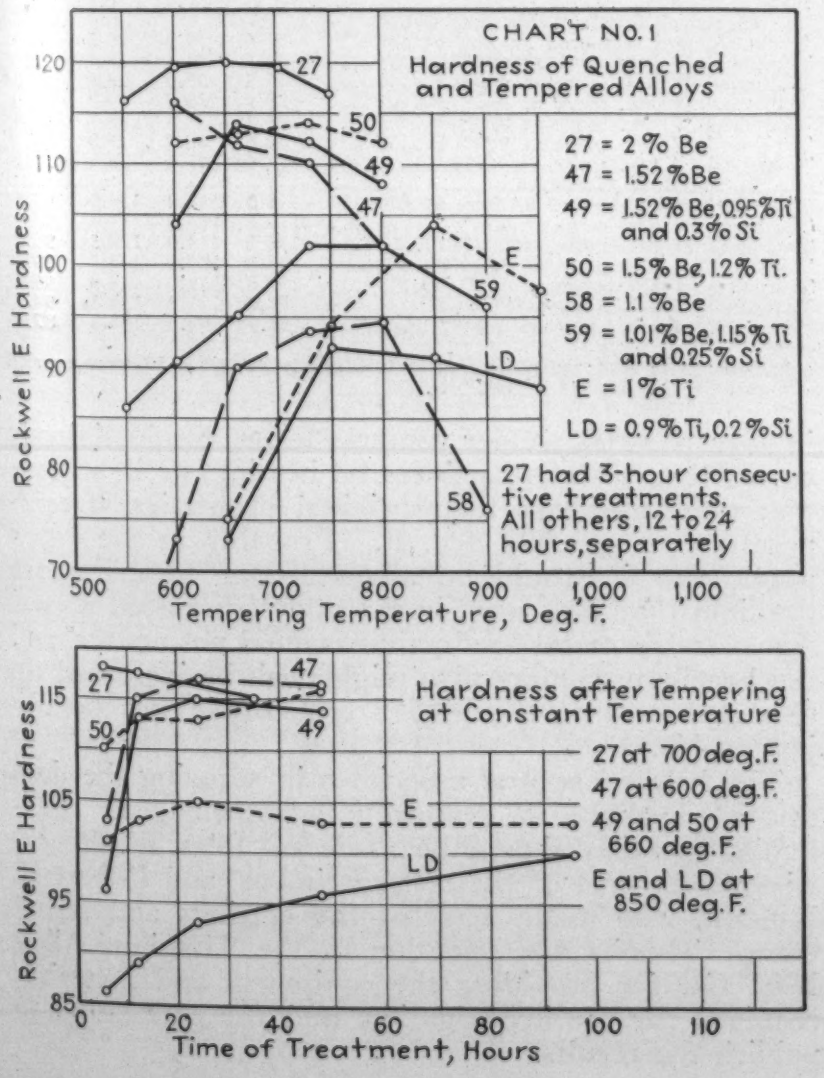


CHART NO. 1
Hardness of Quenched and Tempered Alloys
27 = 2 % Be
47 = 1.52 % Be
49 = 1.52 % Be, 0.95 % Ti and 0.3 % Si
50 = 1.5 % Be, 1.2 % Ti.
58 = 1.1 % Be
59 = 1.01 % Be, 1.15 % Ti and 0.25 % Si
E = 1 % Ti
LD = 0.9 % Ti, 0.2 % Si
27 had 3-hour consecutive treatments. All others, 12 to 24 hours, separately
Rockwell E Hardness
Tempering Temperature, Deg. F.
Hardness after Tempering at Constant Temperature
27 at 700 deg. F.
47 at 600 deg. F.
49 and 50 at 660 deg. F.
E and LD at 850 deg. F.
Time of Treatment, Hours

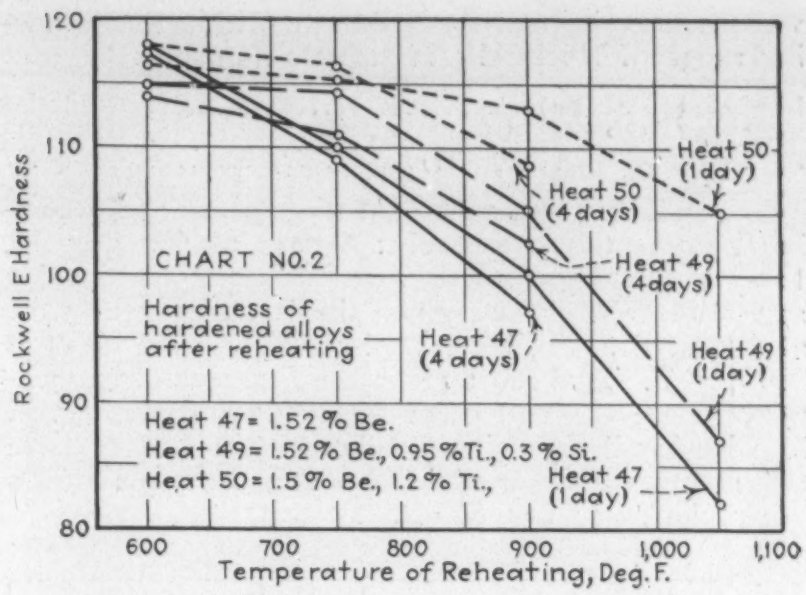

Heat 50 (1 day)
Heat 50 (4 days)
Heat 49 (4 days)
CHART NO. 2
Hardness of hardened alloys after reheating
Heat 47 (4 days)
Heat 49 (1 day)
Heat 47 = 1.52 % Be.
Heat 49 = 1.52 % Be., 0.95 % Ti., 0.3 % Si.
Heat 50 = 1.5 % Be., 1.2 % Ti.,
Heat 47 (1 day)
Rockwell E Hardness
Temperature of Reheating, Deg. F.

Fig. 5. **Hardness of Hardened Alloys after Reheating.**

lium, the presence of that element with titanium seems to have given lower conductivity and no greater hardness than would be expected in similar alloys with titanium alone; and in the alloys with over 1.1 per cent beryllium the presence of titanium seems to have reduced the conductivity slightly without appreciable increase in hardness after heat treatment. Thus as a means of securing the best combination of hardness and conductivity at room temperature after an ordinary heat treatment, the use of both these elements together in copper does not seem worthwhile.

The double quenching temperature given for heats 49 and 50 in Table 2 represents an attempt to secure temper hardening from titanium at 730 or 800 deg. F., and a further hardening from beryllium at 600 deg. F. The choice of temperatures for these tempering treatments resulted from some preliminary work with small specimens which were used for hardness tests only. Examples of the results obtained in this preliminary work are given in Tables 3 and 4 and Fig. 4, in which are included for comparison some data on two titanium-copper heats without beryllium.

From these preliminary tests it was concluded that the maximum hardness of the beryllium alloys containing titanium was developed after a longer tempering period than when titanium was absent, and since it was also known, of course, that the titanium alloys required a higher tempering temperature than the beryllium alloys, it seemed probable that the alloys containing titanium would retain their hardness to

Table 4.—Rockwell E Hardness after Tempering Quenched Alloys at Constant Temperature.

	Tempering Temp.	Time of Treatment, Hrs.					
Alloy—(%)	deg. F.	5 to 6	12	24	35	48	96
E (1 Ti)	850	101	103	105	...	103	103
LD (0.9 Ti, 0.2 Si)	850	86	89	93	...	96	100
47 (1.52 Be)	600	103	115	117	...	116.5*	...
49 (1.52 Be, 0.95 Ti 0.3 Si)	660	96	113	115	...	114	...
50 (1.5 Be, 1.2 Ti)	660	110	113	113	...	116	...
27 (2 Be)	700	118*	117.5*	...	115*	...	...

* Note: These results were obtained from larger specimens; the specimen of heat 27 after the 35-hr. treatment had the following properties: 36.8 per cent conductivity; 86,900 lbs. per sq. in. yield point; 93,800 lbs. per sq. in. tensile strength; and only 0.5 per cent elongation.

a greater degree and for a longer time, when heated, than those free from titanium. Some experiments were therefore carried out to show the softening effect of temperature and time on some of these alloys after they had been heat treated to give maximum hardness. The first tests were made on small sections of castings from heats 47, 49, and 50, that had been hardened by

various experimental treatments to within the following range of Rockwell E hardness numbers:

Heat 47 (1.52% Be)	115 to 118
Heat 49 (1.52% Be, 0.95% Ti, 0.3% Si)	113 to 115
Heat 50 (1.5% Be, 1.2% Ti)	116 to 117

Four pieces from each heat were given the following treatments, respectively: 4 days at 600 deg. F., 1 day at 750 deg. F., 4 days at 750 deg. F., and 1 day at 900 deg. F. Those given the last treatment were also treated again, after testing, for 3 more days at 900 deg. F. And those given the first treatment mentioned were also re-treated for 1 day at 1050 deg. F. The Rockwell E hardness values obtained after these treatments are reported in Table 5, the same values being plotted in Fig. 5.

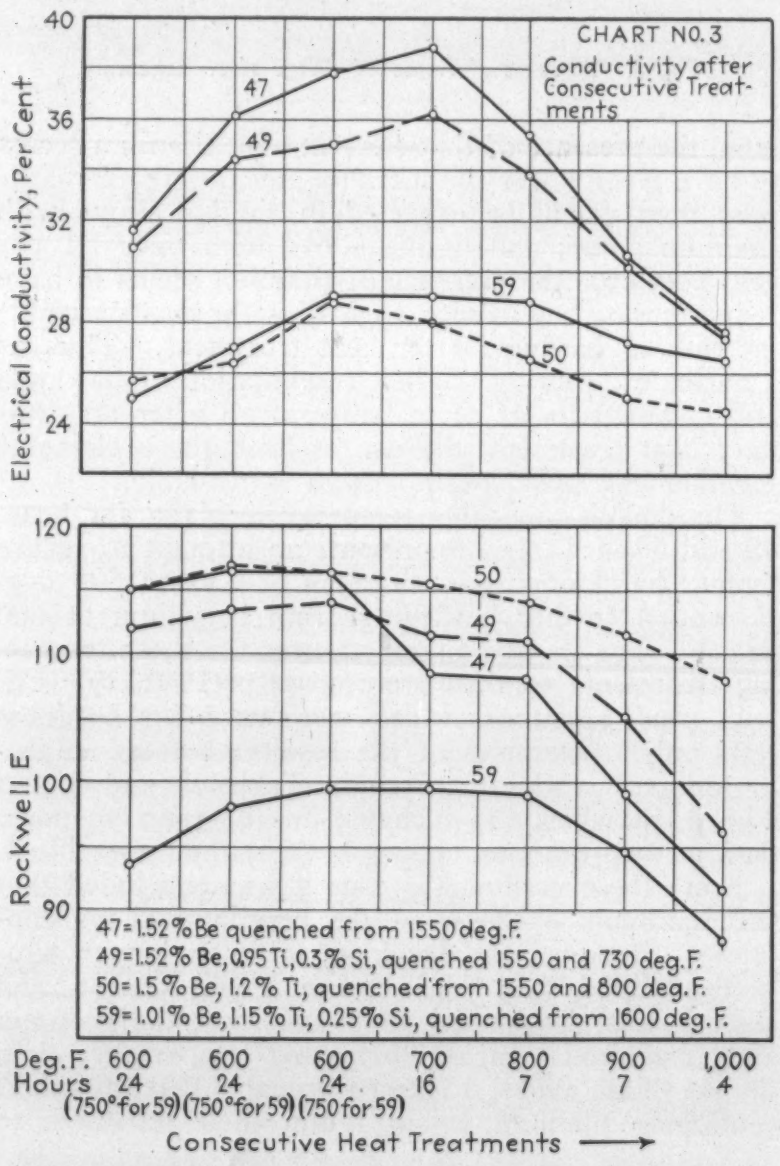


Fig. 6. Conductivity and Hardness after Consecutive Treatments.

This shows that the hardness of the alloys 49 and 50, especially the latter, is maintained at higher temperatures more effectively than that of the plain beryllium-copper of heat 47; or in other words that titanium retards the softening of beryllium copper on heating above the hardening temperature. Similar experiments were repeated with full-sized bars on which the conductivity as well as the hardness could be determined, but with these bars all the treatments on any one alloy were made with the same specimen, the effect thus being cumulative from one treatment to the next. The results of these experiments are presented in Table 6 and Fig. 6.

These results show that these beryllium alloys decreased in conductivity as well as hardness when they were overheated for considerable periods of time. The plain beryllium alloy, without titanium, was the best when tempered at 600 deg. F., but at higher temperatures the hardness of the titanium-bearing alloys 49 and 50 did not drop as fast as that of alloy 47 without titanium. The conductivity of the alloys containing both beryllium and titanium was inferior to that of alloys with each element separately, but the conductivity of the beryllium alloy without titanium dropped more rapidly on over-heating so that, after exposure to 900 or 1,000 deg. F., its superiority in conductivity was negligible. Apparently the beryllium compound goes back into the solid solution at such temperatures, while the titanium-silicon compound does not, since the conductivity of alloys containing only the latter compound and no beryllium is improved by heating up to 1050 deg. F. The low conductivity of alloy 59 with only 1 per cent beryllium is disappointing and

Table 5.—Rockwell E Hardness of Hardened Alloys after Reheating

Alloy Heat No.	47	49	50
Original (24 hrs. at 600° F.)	118.0	115.0	116.5
After 4 days at 600° F.	117.5	114.0	118.0
After 1 day at 750° F.	110.0	114.5	115.5
After 4 days at 750° F.	109.0	111.0	116.5
After 1 day at 900° F.	100.0	105.0	113.0
After 4 days at 900° F.	97.0	102.5	108.5
After 1 day at 1050° F.	82.0	87.0	105.0

seems to indicate that such a small amount of the beryllium compound is not precipitated from the solid solution unless some nuclei of the compound have already been formed by previous precipitation of part of a larger beryllium content.

The function of titanium in beryllium-copper, as shown by these tests, seems to be the stabilization of the hardness at higher temperatures than could be endured, without softening, by the plain beryllium-copper alloy. This might offer a considerable advantage

Table 6.—Conductivity and Hardness of Beryllium-Copper Alloys after Various Consecutive Heat Treatments

Alloy Heat No.	47	49	50	59
Beryllium Content	1.52	1.52	1.5	1.01
Titanium Content		0.95	1.2	1.15
Silicon Content		0.31	0.1	0.25
Electrical Conductivity, Per Cent:				
Quenched and tempered 24 hrs. at 600° F.	31.6	30.9	25.7	25.0*
Tempered 24 hrs. more at 600° F.	36.1	34.4	26.4	27.0*
Tempered 24 hrs. more at 600° F.	37.8	35.0	28.8	29.0*
Tempered 16 hrs. more at 700° F.	38.8	36.2	28.0	29.0
Tempered 7 hrs. more at 800° F.	35.4	33.8	26.5	28.8
Tempered 7 hrs. more at 900° F.	30.6	30.2	25.0	27.2
Tempered 4 hrs. more at 1,000° F.	27.6	27.4	24.5	26.5
Rockwell E Hardness:				
Quenched and tempered 24 hrs. at 600° F.	115.0	112.0	115.0	93.5*
Tempered 24 hrs. more at 600° F.	116.5	113.5	117.0	98.0*
Tempered 24 hrs. more at 600° F.	116.5	114.0	116.5	99.5*
Tempered 16 hrs. more at 700° F.	108.5	111.5	115.5	99.5
Tempered 7 hrs. more at 800° F.	108.0	111.0	114.0	99.0
Tempered 7 hrs. more at 900° F.	99.0	105.0	111.5	94.5
Tempered 4 hrs. more at 1,000° F.	91.5	96.0	108.0	87.5

* Note: The first three tempering treatments on alloy 59 were carried out at 750° F. instead of 600° F.

in such parts as welder contacts where conductivity is essential as well as hardness on heating, or in springs that must maintain their original properties at temperatures above 600 deg. F. Probably in the latter application it would be advantageous to use more titanium than was used in the alloys discussed above, since low electrical conductivity would not matter, and the beryllium content also might well be increased up to 2 per cent if the higher cost would not be objectionable.

The help of several associates in securing the data presented above is gratefully acknowledged. Particular mention should be made of John W. Boeck, who made some of the test specimens, and Robert E. Bannon, who made most of the castings and tested them. Thanks are also due to the Titanium Alloy Mfg. Co. for providing the equipment and materials required for the investigation, and for permission to publish the results.

DEFECTS IN WROUGHT BRASS

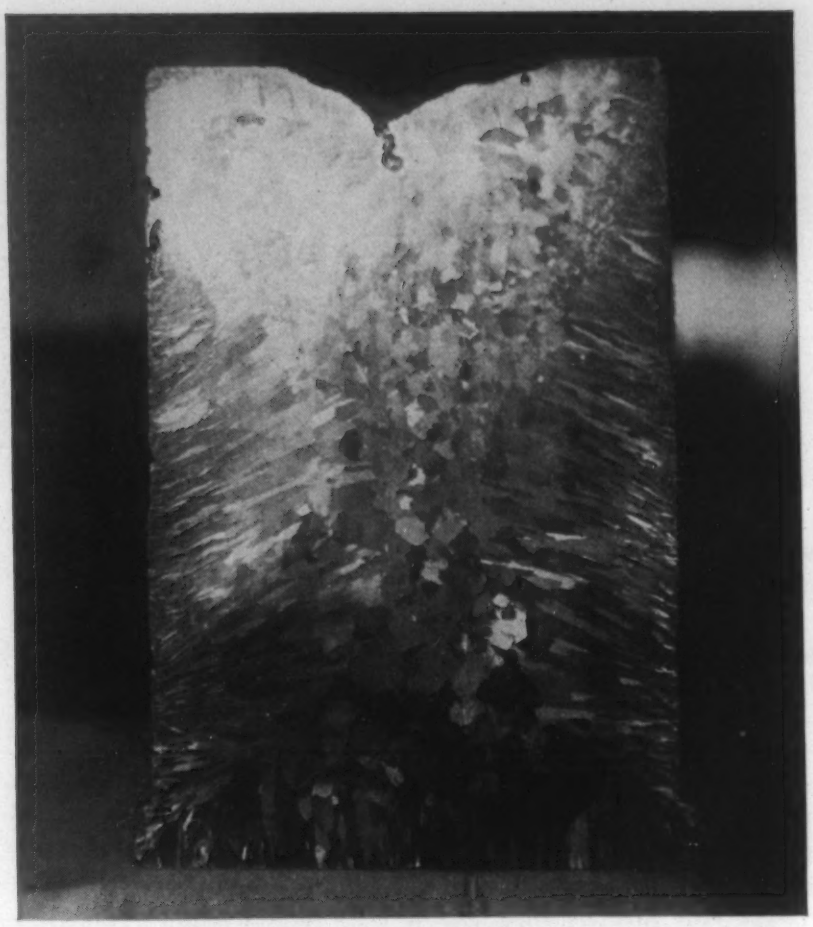


Fig. 1. Sample of Metal Taken with a Scoop.

Is Melting or Pouring Practice Chiefly Responsible?

By L. KROLL and E. A. ANDERSON

Metallurgists, Dallas Division, Revere Copper & Brass, Inc.

IN THE ATTEMPT TO CONTROL the quality of wrought brass, one may examine the product at any stage of fabrication. The ingot can be either gated, that is, sections are cropped from the top part on, to detect and remove defective metal or notched, fractured and examined, or it can be forged or rolled part way down and given a light anneal then manufactured and examined (since some shrink cavities and other peculiar appearances or structures of no importance to the final casting quality close up on such treatment), or it can be taken clear down to strip and a large sample fractured on the patent leveling machine, or deep flanged shells can be drawn from the stock. When defects arise, the question always comes up, were the defects in the metal itself, or in the pouring practice?

If the trouble is inherent in the charging stock or in the furnace atmosphere, for example, we should turn our attention to those factors while, if the metal itself is beyond reproach, but we have spoiled it by sloppy skimming or pouring, by poor mold surface or the wrong mold dressing, it is those features that should be remedied. In order to tell into which group of reasons for trouble we should look, it is worth while to study the metal itself, free from the variables of pouring. If inclusions or gas that will be given off during freezing are in the metal itself, it is worth while to know it, while if the inclusions come from entrapped dross, or mold-dressing residues and the gas is merely air trapped in pouring or that from the cracking of the mold dressing, we should not blame the metal.

In order to sample the metal a closed end tube with a side opening to prevent catching dross, called a "scoop" in shop parlance, may be used. The tube is heated to the same temperature as the metal, plunged into the metal, filled and removed to cool. Our first tube was a clean 2-in. iron pipe, closed at the lower

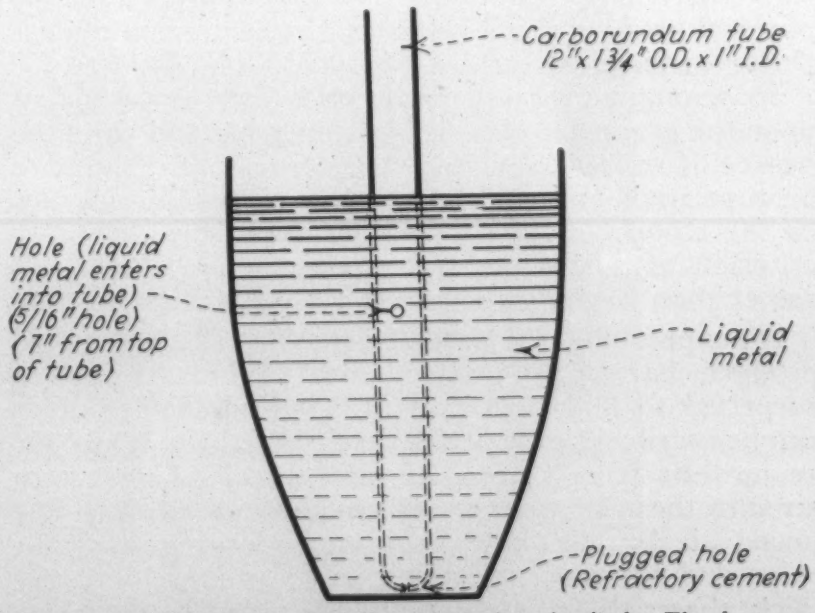

Carborundum tube
12"x1¾" O.D.x1" I.D.
Hole (liquid metal enters into tube) (5/16" hole) (7" from top of tube)
Liquid metal
Plugged hole (Refractory cement)

Fig. 2. How the Scoop Sampling Method is Applied. The hot carborundum tube, at the same temperature as the liquid bath, is immersed in the hot metal.

end with a nipple. This was withdrawn and either allowed to cool under retarded cooling, in air or plunged slowly into a pail of water so as to freeze the

Fig. 3. A Contact Print to Show Porosity.

metal from the bottom up. A sample taken with such a scoop is shown in Fig. 1 at 2X. The test was consistent when used on copper. Gassed metal would show gas holes in the scoop test, and the rate of freezing made no appreciable difference in the results.

The outfit now in use on brass is shown in Fig. 2. This shows a crucible, though the equipment is, of course, used also on the Ajax-Wyatt furnaces. After the scoop has been filled, it is slowly withdrawn till the metal above the side hole has run back into the melt and the tube is tilted a trifle to let a bit more metal run out so that there will be no metal freezing in the hole.

The tube and its contents are then allowed to cool. In the case when the slug sticks in the tube the cement may be dug out of the plugged hole in the bottom and the slug shoved out. This gives a 1-in. diam., 5-in. long sample representing the molten metal.

The pipe and the surface may be examined, the slug may be sectioned as it is, or it may be forged, annealed, notched and fractured.

A contact print to show porosity is shown in Fig. 3 of the cross section of a flat poured from the same heat as Fig. 2, but with wrong mold and pouring conditions.

Saeger and Ash[1] have used a tapered graphite scoop for sampling copper base alloys for sand castings. With certain precautions, explained by them, it is possible to determine the liquid shrinkage by such a specimen, and it can be made large enough to give a standard tensile test bar. They have shown that the physical properties of such a test bar are generally superior to those of bars cast in sand.

In wrought brass the properties are so dependent upon the grain size obtained by annealing and upon the degree of reduction, that we considered it for the moment relatively unimportant to take physical properties on the scoop samples. We have used them only as a criterion of soundness and freedom from inclusions, rather than to supply a sample for mechanical testing.

We expected that at least a few melting features would produce characteristic defects in 65:35 brass, but were surprised to find that it is rare indeed that troubles can be ascribed to the metal itself. We have taken out scoop tests from 1815 up to 2100 deg. F., have blown air into the melt, blown city gas through it, have followed air by gas, have compared virgin metal with chips and turnings, used very oily turnings, thin and thick charcoal covers, various slags and deoxidizers, etc., etc., and the scoop test always came out without gasiness or inclusions. The only thing we have found to give bad metal in the scoop test is high sulphur. Saeger and Ash found a decrease of tensile strength in red brass with over 0.05 per cent sulphur, especially at high pouring temperatures. Inclusions due to very high sulphur (0.14%) in our tests on yellow brass are shown in Fig. 4 (unetched, 200x).

It is quite thoroughly accepted that hydrogen containing gases cause unsoundness in many copper base alloys, but in the case of straight brass, high in zinc, we have not been able to detect any gassing even when city gas, which is, of course rich in hydrogen, is blown into the melt. Genders and Bailey[2] comment on the insensitivity of the high zinc brasses to hydrogen, while bronzes are very sensitive.

Our experience with the scoop test leads to the conclusion that melting practice is far less likely to be

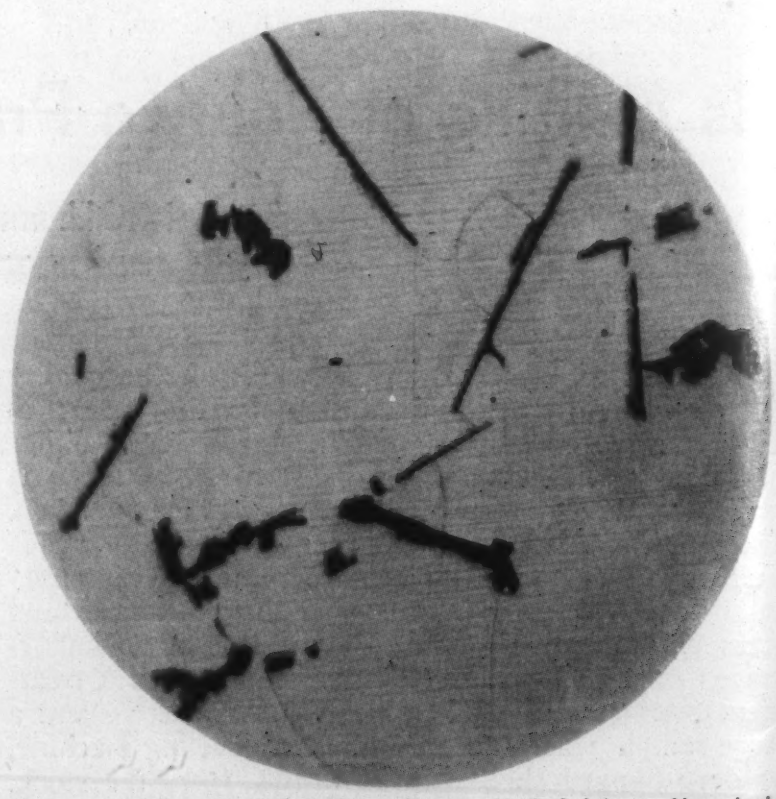


Fig. 4. Inclusions in Yellow Brass Due to High Sulphur. Unetched. Magnification 200 diameters.

responsible for defects in brass than are such factors as turbulent pouring, splashing, poor mold surface and wrong mold dressings. This checks the findings of R. Genders and G. L. Bailey. To lay the blame on the metal before the pouring variables have been brought under control is to strain at a gnat and swallow a camel.

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[2] R. Genders and G. L. Bailey. "The Casting of Brass Ingots," British Non-ferrous Metals Research Assn., London, 1934, page 108.

Metallurgical Needs of the Glass Industry—II

By R. D. SMITH

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Concluded from the September issue

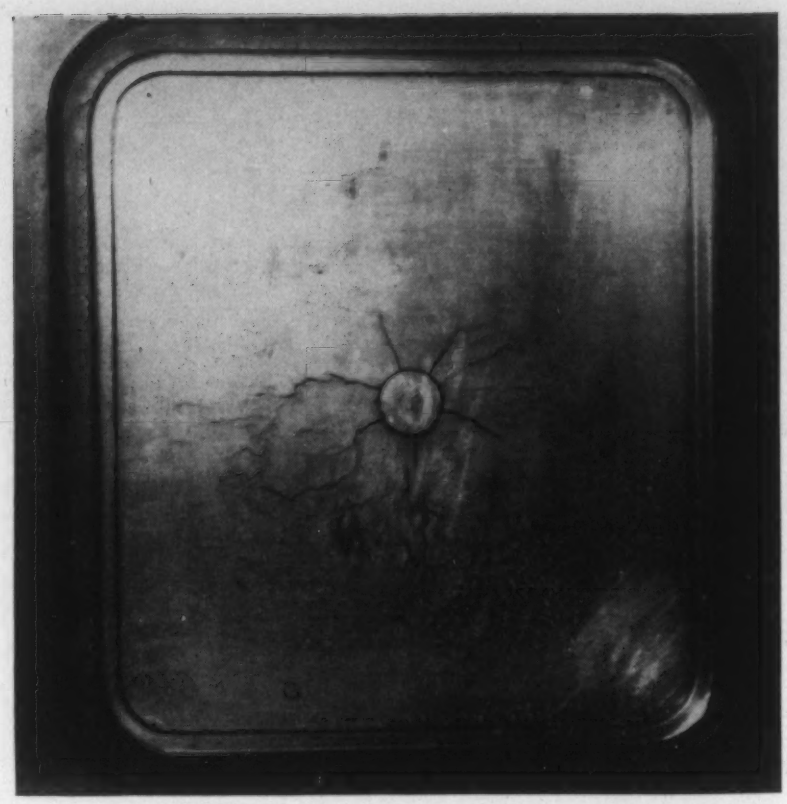
Materials for Molds

THE glassmaker still uses gray cast iron for making the bulk of his molds. This continued use of cast iron is not because the glassman is unaware of the special alloy irons, stainless alloys and surface treatments at hand. The glass manufacturer was using stainless steels for molds in 1920, and many other alloys and even chromium plated molds have seen service during the past 15 years. The glass manufacturer also welcomed nitrided nitralloy as soon as this material and process was perfected and placed on the market.

Molds of Gray Iron

The low initial cost, ease of machining, with low inventory and obsolescence charges, while strongly in favor of the gray cast iron are by no means the only reasons for continued use of that material for glass molds. Due to the increased demands on the molds either by increased production or

A Blown Glass Tub, Still on the Blow Iron.



Surface Checks on the Pressing Face of an Oven Door Panel Mold.

quality of ware, glass manufacturers are, in general, dissatisfied with the performance of gray cast iron molds and are continually searching for better materials. Some of the alloy irons supply certain properties required for molds and are used when these requirements are pre-eminent. Steels and alloys of the stainless type are used for their resistance to oxidation and greater useful life before developing heat-checked surfaces. The main obstacle to the extended use of these special materials is that the important thermal properties of the latter differ markedly from those of regular gray iron about which the glass pressing cycle, and hence glass machines, have been developed.

Furthermore, the so-called high test irons and alloy irons, which have performed so well in commercial applications, have been found rather disappointing to the glass trade in respect to their ability to withstand the thermal fatigue with its resultant heat checking of the mold surface. This latter observation is particularly true of press molds in which the glass is pressed in one operation to its finished shape, as compared with press and blow molds in which the glass blank is either pressed or blown from one set of molds to a semi-set condition followed by a transfer to the finish or blow mold. The latter process is essentially that used for making bottles. While many other desirable mold properties are similar to press and bottle molds, it by no means follows that one type of material is suitable for both types of molds.

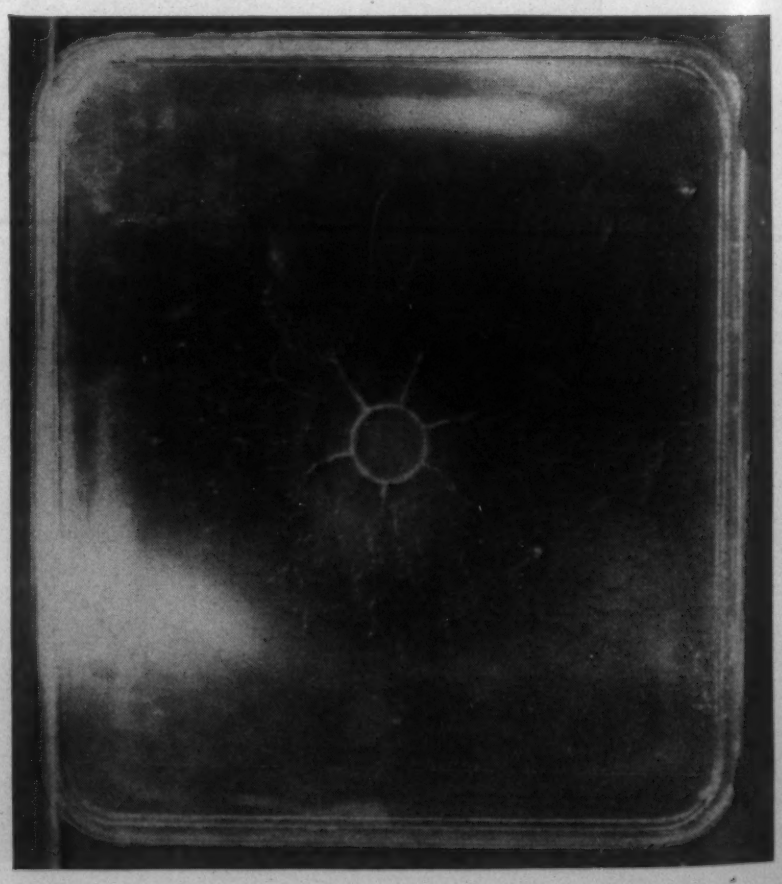
Since the function of the mold is to form the glassware to shape, it will be in order to describe some of the properties[2] of glass and mold materials of importance in this process. While glass in its molten state can be made to flow from an orifice in a forehearth, be sucked up into a "parison" or blank mold from a molten pool, or gathered on a blow pipe or punty iron, it is not generally free flowing and becomes progressively more viscous as it is drawn from the working end of a melting unit. In general the viscosity of a glass of the soda-lime type doubles for each 55 deg. C drop in temperature around 1200 deg. C. At the annealing range, which is from 500 to 550 deg. C, the viscosity doubles for each 8 to 9 deg. C drop in temperature.

While there is sufficient mobility to permit annealing of the glass in this lower temperature range, and some limited reforming operations may be made at 650 deg. C, the true working range is a limited field of somewhat higher temperature. This working range varies with the different glass compositions and the glass may have a "short" or "long working range." Below the working range the glass is rather tender and susceptible to cracks or checks. Glass is strong under compressive stresses and weak under tensile stresses. Glass also has a tendency to wet or stick to hot metal surfaces varying as to the sticking temperatures with glass or metal composition.

Repeating that it is the function of the mold to form the glassware, the importance of the mold temperature in the glass forming cycle becomes more apparent. Means for cooling the molds after the release of the ware is provided with air, wind, or water jacket. While the mold may be returned to the glass receiving position at the desired surface temperature, the rate of heat flow determined by the thermal properties of the metal and oxide film seriously affects the setting up cycle of the glassware. If the mold is too cold, the ware may have a chill wrinkled surface, not blown or pressed up fully to shape, or be checked in the process of shaping. With the molds too hot, the fault may be in sticking of the glass at some part of the mold interfering with release of the ware thus resulting in checking, deforming, or mold scale adhering to the ware. The heat transfer from glass to metal is also affected critically around glass to metal sticking temperatures. The more intimate the glass-to-metal contact, the more rapid is the flow of the heat from the glass to the metal. The factors promoting this intimate contact are: Hot glass and hot mold body temperatures, pressure of glass against mold surface, mold surface polish, and, of course, time of contact.

The above description will tend to bring to the reader's attention some of the difficulties in substituting one mold material for another, and the differences in blown and pressed ware forming of glassware.

Glassware Pressed into the Surface Checks of the Mold of an Oven Door Panel.



It will also be apparent that a decreased life of molds may be due to the very slight changes in the operating conditions in order to improve ware quality as well as the rate of increase in output from molds.

Factors Limiting Life of Molds

In order to displace gray cast iron as glass mold material with special cast irons or special alloys, we must first be assured that, for the service intended, the proposed material will offer advantages over the gray iron resulting in better and longer mold service. Assuming that a new mold is satisfactory for forming glassware on a given glass machine, some of the factors limiting the continued use or ultimate life of the mold are:

The mold surface oxidizes or becomes dirty in service and must be cleaned. This oxide film eventually affects the heat transfer balance and results in sticking, checking, or adherence to the glassware of metallic oxide.

The mold may develop a heat checked surface due to the thermal fatigue received in the cycle of heating by the glass and the artificial cooling.

The failure may be by warpage or growth, by loss of sharp pointings, joints or other faults caused by wear.

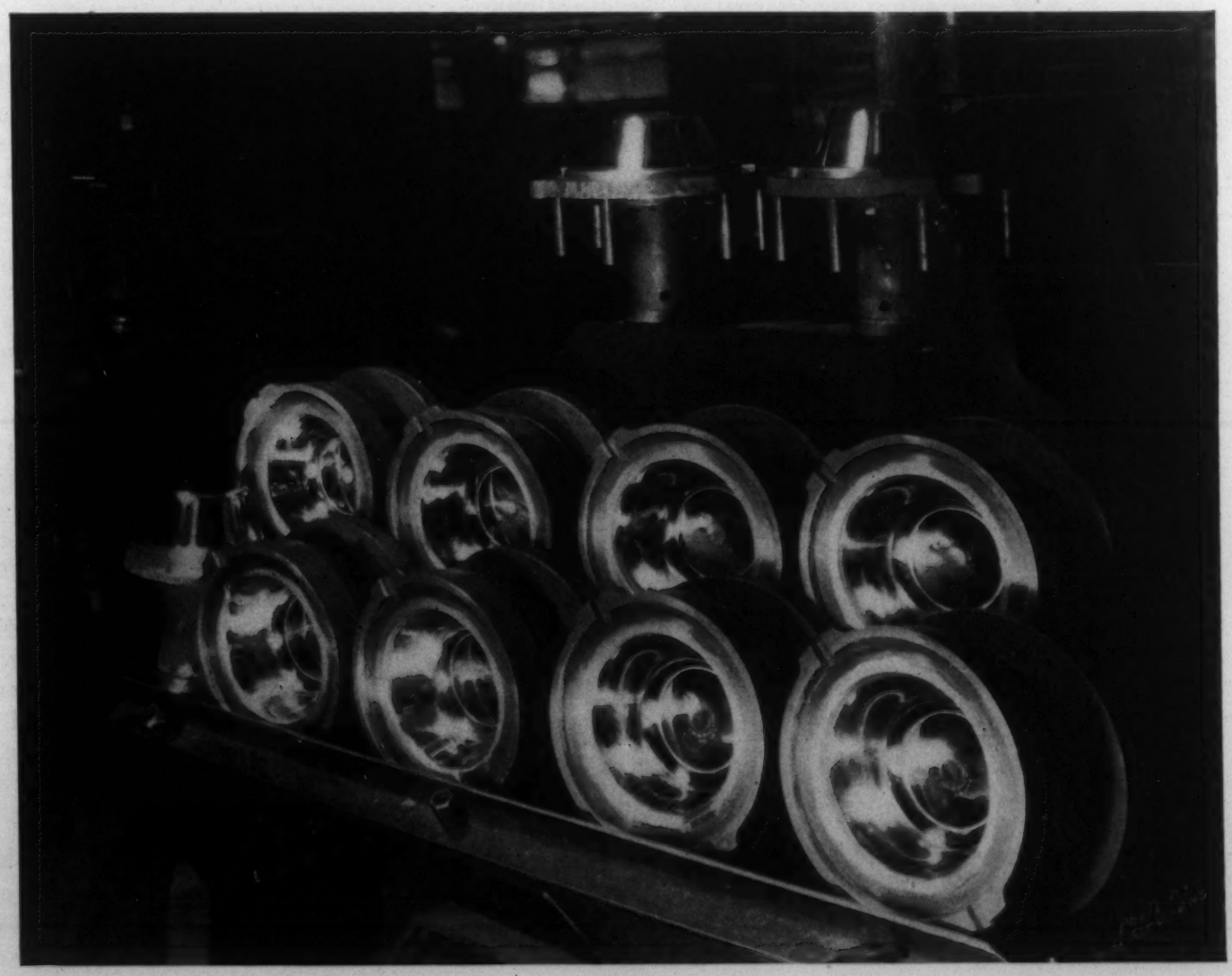
Repeating the observations concerning the performance of high test or special alloy irons as mold material in that such special materials only partially meet mold metal requirements and do not appear to offer increased resistance to heat checking of the mold surface, it will be necessary to elaborate further.

Certain molds of the hot iron type, of which the bottle mold[3] is a typical example, and which parts are usually the half shape of the article or section of the glassware to be shaped, must possess freedom from warpage and growth, and also those physical properties which give resistance to wear and retention of sharp edges and joints. The tendency of such shapes to heat check is not so pronounced as with block shaped or press type molds. High test alloy and high temperature cast irons of fine uniform structure are of distinct advantage in such mold shapes provided the alloy does not seriously affect expansion or thermal conductivity.

Some Facts About Press Molds

With press molds or solid molds the resistance toward heat checking of the mold surface is of chief importance particularly with large mold shapes. Little difficulty is experienced with warpage or growth during the life of the mold. In fact, the high carbon-high silicon cast irons, which the customary growth tests at elevated temperatures would tend to eliminate from consideration, are actually the best performers in resistance to heat checking by actual tests as mold material, comparing favorably with service from the low carbon-low silicon iron with or without alloy additions. It may be well to add that the analysis of two different gray irons may be almost identical and the service life decidedly different. In general, the proper blending of the irons in a cupola or furnace charge and the absence of steel or other low silicon scrap appears to be important in the process of producing press mold castings. The presence of considerable phosphorus in the gray iron castings does not appear to be detrimental.

There are some foundries which make a specialty of press mold castings. Very few glass manufacturers order glass mold castings of the hardware iron type but buy them from the foundries specializing in that line of work. The high silicon-high carbon gray irons are cast against a chill to obtain the desired glass forming surface. With press molds the chill is always used and is necessary on all irons except those melted at very high temperatures and in which the graphite is



Plated and Polished Press Molds.

naturally thrown out in a very finely divided condition. Experience with low carbon-low silicon and similar alloy irons cast without chill indicate that for press molds the surface is not sufficiently close grained for good press ware finish. There is a tendency for such unchilled irons to open up on the surface rather early in service. With blow molds, the importance of chilled iron surface is not so great since the service does not appear to open the grain and the surface pattern may not be so faithfully transmitted to the blown ware surface.

Both the glass manufacturer and the foundryman recognize that the special irons developed for other purposes do not fill all the requirements of glass molds. Attempts are now being made to develop suitable cast irons with the cooperation of the research and development staffs of the metallurgical industry.

Analyses of cast irons tried out as press molds in one comparative test at Corning are given in Table II. These analyses were made by the Vanadium Corp. of America in the course of an examination of the molds and are presented with the kind permission of Jerome Strauss, vice president of the company.

Table II.—Analyses of Cast Irons Tried Out as Press Molds

Material	T.C.	G.C.	Si	Mn	Cr	Ni	S	P	Other
A-1926	3.58	3.32	2.42	0.59	None	None	0.039	0.428	
A-1934	3.50	3.44	2.22	0.55	0.06	None	0.058	0.410	
A-Mo	3.50	3.34	2.76	0.74	0.08	None	0.023	0.310	0.28 Mo
B-1	3.70	3.30	1.99	0.57	0.07	None	0.053	0.250	
B-2	3.50	3.04	2.20	0.58	0.12	3.43	0.044	0.230	
B-3	3.57	3.19	2.27	0.58	0.06	1.92	0.044	0.230	{1.98 Al
C	2.93	2.51	3.36	0.21	1.99	0.85	0.021	0.032	{0.21 V
D	2.75	2.23	2.34	0.41	1.74	14.73	0.103	0.210	6.03 Cu
E	3.38	2.75	1.32	0.49	0.29	1.43	0.093	0.140	
F	2.99	2.46	2.30	0.50	0.45	1.84	0.047	0.240	
G	2.53	1.84	2.15	0.60	0.09	None	0.049	0.062	
H	3.81	3.39	1.84	0.58	0.10	None	0.055	0.240	
I	2.11	1.65	0.90	0.80	0.04	....	0.043	0.180	

In explanation of Table II, it may be stated that a certain press mold part which undergoes severe service was selected for the test. Six molds were ordered cast in each composition or range of compositions from the respective foundries. Four such mold parts were used in the mold set and so far as possible the set was made up of four different materials arranged in such a manner as to give a comparative test. The production and hours service was recorded and glassware from the molds examined. The latter identification was obtained by a lettered code stamped in the mold. The orders for rejection of the mold, due to ware defects from mold causes, was left in the hands of the inspection department. A few of the irons could not be operated with the regular gray iron due to thermal properties which demanded different cooling conditions. These materials were operated separately to conform to the best service conditions suited to the mold material.

The A type of iron gave the longest satisfactory service life which averaged 20 hrs. The A-Mo iron was not as long lived as the regular gray iron. The poorest service was obtained from the G, H, and I irons. The I iron checked before coming to operating temperature and never pressed a passable piece of ware. The G and H irons gave only 8 and 6 hrs. average life.

The B-1 set of molds was between the A and G type in length of service. The shape of the mold was not quite a fair test for C type iron[4] which cracked in service after an average of 16 hrs. Subsequent tests in mold shapes adapted to the properties of this alloy iron indicate that this material shows promise as a mold iron. The rest of the alloy irons B-2, B-3, D, E, and F all gave a better account of themselves than G, H, and I but failed to measure up to the A type in performance for one reason or another.

It may be generally stated then that the alloy irons are better than average gray irons but not proven superior as yet to good mold gray iron. While we were able to obtain a good total life from some of the alloy irons, yet in the middle of an 8-hr. move, there was an opening up of the surface so that a change of molds was necessary. A severe stoning removed this surface but the fogging of the pressed ware appeared to occur a little sooner on the next service run of these mold parts. The particular offenders were those irons which are customarily cast without chill.

Molds of Stainless Steels

Stainless steels[5] find use as mold materials where short checking life and excessive oxidation of cast iron parts are so objectionable as to counterbalance the higher initial cost and operating adjustments necessary to the use of the special alloys. Since these mold parts may be used in conjunction with cast iron, the relative expansion of the two materials is important. In general the straight chromium steel, only mildly alloyed for certain properties, appears to fill the mold requirement better than the chrome-nickel stainless steels. The expansion coefficient appears to affect the checking life. The 13 per cent chrome steel, or the non-austenitic type, is the most useful mold material.

The stainless steels may be obtained as forgings or as castings. The forgings appear to give a longer life than castings although it must be stated that considerable improvement has been made in the quality of castings. For glass molds the pressing face must machine without the slightest imperfection. It is unsatisfactory to have to patch up sand holes or to have a segregated structure which will polish unevenly. Patches always show on the glassware, being opened up at the joints by the heat.

Chromium Plated Molds[6]

The real advantage of chromium plated glass mold surfaces is not always understood.[2] The increased resistance to oxidation given to a mold surface is the apparent advantage. The plated iron or mild steel mold does not take the place of stainless steel in its resistance to heat checking but it does present the property of resisting the sticking action of hot glass and permits the highest mold operating temperature. Stainless steels on the other hand are the worst offenders as regards sticking to glass at a minimum temperature.

The ability to obtain and to retain a high polish on mold surfaces is an advantage inherent in stainless steels and on chromium-plated surfaces. While the high polish tends to produce better ware finish, it also affects the intimacy of glass contact with metal and affects the sticking of glass to metal adversely as compared with a moderately polished surface. In this connection a cast iron, containing 3 per cent graphitic carbon by weight, presents a pressing surface containing 10.5 per cent of exposed graphite which assists in freeing the glass from the mold surface. All of these conditions must be considered in evaluating the relative sticking of glass to mold surfaces.

Paste Blow Molds

Some thin walled hollow glass articles such as electric light bulbs, beakers, flasks, cylinders, and

chimneys are desired free from mold seams and with a high surface finish approaching that obtained by blowing glass in the air free from metallic mold surface contact. Such shapes may be blown in paste molds. The glass shapes must be symmetrical to the vertical axis since a relative rotation of glass and mold is made about that axis during the blowing operation.

The molds are somewhat similar to hot iron blow molds in that they are jointed or split along the vertical axis to form the half round shape of the ware to be blown therein. The inner mold surfaces are coated with a baked-on layer of linseed oil and carbonized cork dust or willow charcoal. Water is used to treat the mold surfaces between blowing operations so that, when the plastic glass blank is blown against the mold surface, steam is generated to form a controlled cushion and chilling medium. The ware formed is free from mold seams due to the relative rotation of glass and mold and possesses a good surface lustre.

The operating temperature of paste molds is not so high as is obtained with hot iron blow molds so that heat checking is not the cause of failure. The effect of the steam becomes apparent in growth and warpage, however. This warpage may be overcome by design of the molds in providing reinforcing ribs on the gray iron molds or by use of other cast irons less susceptible to the action of steam. A reduction in the silicon and carbon is beneficial with such cast iron molds. The use of nickel cast iron or the use of malleable iron molds will overcome the warpage. Since molds of this type are machined in large numbers by forming tool methods, the ease of machining is relatively important. All castings should be annealed prior to final machining to eliminate warpage from casting stress source.

Improved Mold Service

The mold failure by surface heat checking has been stated to be caused by the alternate heating and forced cooling. The heating by the hot glass cannot be avoided. The severity of the service could be lessened by reducing the frequency of the cycle and by the elimination of the excessive alternate cooling. The lessening of the frequency could be obtained by reduction of the speed of the machine or by increasing the number of molds, both of which alternatives have serious objections or limitations.

The severity of the alternate cooling can be reduced in several ways. The reduction in machine speed and increasing the number of molds as previously stated are the more obvious methods although they are the ones which will meet with the greatest opposition and which can be considered only as a last resort. The use of heavier mold sections or ribbing to increase the natural heat loss by radiation is another method of reducing the forced cooling on the mold face, while properly proportioned mold sections with controlled outside mold cooling is the most promising means of reducing the severity of service.

As stated above, the reduction in speed of the machine will not be tolerated. In the case of the conventional glass machine, rotating in a horizontal plane, an increase in the number of molds means an increase in the diameter of the machine and a corresponding crowding at the forehearth or working end of the furnace. Straight line types of machines or those types which present to the furnace one end of an elongated path of mold circuit are more readily adapted to such increases in the number of molds. Heavy molds are objectionable, due to the excessive weight of the moving parts and clearances between molds. Since glassware of different sizes may be made on the same machine the space between mold holders would eliminate heavy walled molds, or limit the size of ware to be made on the machine. The use of heavy molds or an increase in the number of molds for a given production rate causes an increase in the time required to bring the molds to operating temperature. Mold kilns are used to preheat molds in order to lessen the warming up period.

The blowing of cooling air onto hot mold surfaces, as is often performed in the process of cooling molds, produces a reversal of stress on the mold face while cooling of the outer mold wall tends to maintain the compression of the mold face. In blowing air onto the mold face, some parts of the surface desired hot may be overcooled and it is difficult to return the mold to receive a glass charge with a pre-determined surface temperature and a controlled temperature gradient in the mold body. With the latter type of cooling the flow of heat may occur in two directions in the mold wall in such a manner that, as the heat from the glass tends to travel into the mold body, it is met with a surge from the layer of metal beneath the mold surface.

Experiments conducted with mold plungers, which are internally cooled with air or water and occasionally with liquid metals, have shown that increased plunger life and better pressing conditions may be realized by careful design of the internal cooling area. The same principle of cooling may be applied to molds with outside cooling provided the glass machine will accommodate this method of cooling.

In General

It may be stated generally that there is much room for improvement in glass mold cooling methods and that few machines and molds have been designed from the standpoint of best mold life and service, and, further, that it would be possible to obtain better mold life and also better glass production by more attention to the proper coordination in machine and mold design with mold cooling methods. Only by such a program will the glassmaker be able to fully utilize the improved wares which the metallurgical industries have available.

The author wishes to thank his associates in the development department of the Corning Glass Works for the guidance and assistance rendered in the pursuit of many of the problems outlined herein and for the many helpful suggestions made in the preparation of this article.

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[4] U. S. Patent No. 1,814,102.
[5] U. S. Patent No. 1,449,789.
[6] U. S. Patent No. 2,018,814.

Comments on Mr. Smith's Article

ADVANCE proofs of Mr. Smith's article were submitted to several interested parties for possible comment. Some of those received are reproduced here as follows:

From R. H. Frank, metallurgist, Bonney-Floyd Co., olumbus, Ohio—

> The author deals sparingly with glass plungers. We have experimented with plungers, with the idea of producing one which would wear longer at the shoulder, where the stripping ring rubbed, and of improving the appearance of the pressed ware.

A high carbon chromium steel (0.70% C. 14.00% Cr.) containing 1.00 per cent Mo was found to be satisfactory for resistance to wear and appearance of the glass, but considerable difficulty was encountered in the glass sticking to the plunger. This was entirely overcome by re-designing the cooler, after which they far outlasted the cast iron plungers.

Due to the cost of the material, the difficulty of machining and the inability to bore the cored holes for the cooling glands, such plungers have not, however, replaced the usual ones.

From J. H. Wright, president and general manager, Libbey Glass Co., Toledo, Ohio—

The following information on our practice may be of interest in connection with the excellent article by Mr. Smith.

1. The blow iron tips in our plant are made from gray cast iron which are welded to seamless steel tubing of various sizes.

2. Our punty irons are made from open-hearth black iron by upsetting the end of the iron to form an enlarged ball or a pear shape. We very seldom use clay tipped punty irons, and have found in our practice that the clay tips are rather troublesome. They have been used only in certain special cases, but for all ordinary kinds of ware the plain iron is used.

3. On the Westlake machine the neck mold and knife are made from low carbon machinery steel. The orifice of the neck mold and the cutting edge of the knife are faced with stellite, which is the only satisfactory material we have found which will stand up in practice. The blank molds into which the glass is sucked on the Westlake machine are made from a brass alloy known as Minox Grade A, made by the Binney Castings Co. The plunger tips are made from Minox Grade DV, also produced by the Binney Castings Co. These two materials reduce oxidation to a minimum, and in our opinion is one of the major factors contributing to the success of the Westlake machine.

Editor's note: According to Woldman and Dornblatt, "Engineering Alloys," the non-ferrous alloys referred to are:

	Cu	Al	Zn	Fe	Mn	Ni
A	80	7	5	3	3	—
DV	62	7	7	—	—	22

From H. N. Booker of the Hocking Glass Co., Lancaster, Ohio, the following comments have been received:

It was easy to make a "thorough study" of Mr. Smith's article for it is a most interesting and well written discussion of a very complex problem.

I find the article not only covers the subject more completely than any I have seen, but does it with complete and accurate detail; especially so in the materials for molds in which I have been most interested. In many cases it confirms observations which heretofore could, at best, be called merely theories. There are, however, three questions which I would like to raise.

Little was mentioned in the article about the variation in the tendency of certain metals to "check" hot glass. When speaking of rolls for rolling glass, Mr. Smith does say "The rolls are water cooled and it is impossible to obtain a smooth top glass surface with top rolls of high thermal conductivity materials. . . . It is apparently the low rate of thermal conductivity which is necessary in obtaining a good rolled glass surface, since regulations of the wall thickness and amount of cooling fails to make a regular steel roll satisfactory."

In both the tendency to check, and the example of the rolls, I wonder if it isn't the rate of temperature progression as indicated by thermal diffusivity which predicts the desirable characteristics wanted here, rather than the rate of heat transfer as indicated by the coefficient of thermal conductivity. If it is wholly thermal conductivity which governs, it seems that, since the thermal conductivity of the materials which could be considered for rolls, is of the same order as that of ordinary steel or cast iron, the variation in effect could be taken care of by regulating the wall thickness or amount of cooling.

Referring to the tendency to check, assuming the same glass temperature and the same material temperature, materials tend to check hot glass about in the order name below, the first being the least liable to check:

Copper
Aluminum
Graphite (solid block)
Brass
Steel

This order is approximately the same as though they were listed in the order of their thermal diffusivity—copper having the highest or about 4.2 $\frac{ft.^2}{hr.}$ and steel the lowest or about 0.55 $\frac{ft.^2}{hr.}$. If they were listed according to their thermal conductivity the order would be:

Copper
Aluminum
Brass
Steel
Graphite (solid block)

The changing position of the non-metal lends credence to thermal diffusivity rating. Although the best metal for the work may differ widely with the application—chrome steel for top rolls, copper for handling glass to prevent checking—it appears that their choice rests more upon considerations of thermal diffusivity than upon thermal conductivity.

In the discussion of stainless steels as a mold material Mr. Smith says, "the 13 per cent chrome steel, or the non-austenitic type, is the most useful mold material." Such tests as I have witnessed have been of too short a duration to experience any surface checking, but they did indicate a superiority for the austenitic types including 2 to 3 per cent silicon from the standpoint of resistance to scaling. The number of pieces per mold per polish was in the order of two to one in favor of the austenitic types.

It is stated that "the severity of the service could be lessened by reducing the frequency of the cycle and by the elimination of the excessive alternate cooling." This statement is, without a doubt, strictly true since reducing the frequency of the cycle lowers the number of stress reversals, and elimination of the excessive alternate cooling lowers the differential between maximum and minimum stress at the inner face. It may, however, also be true that reducing the frequency of the cycle lengthens mold life only with respect to hours of service and not with respect to total pieces of ware made. In other words, with the intensity of the stress remaining the same, the total number of stress reversals before reaching the fatigue limit, might be the same regardless of the number of pieces made per mold per hour.

It also seems to me, possibly somewhat paradoxically, that under some conditions, not at all unusual, that the severity of the service could be lessened by increasing the frequency of the cycle. This is apparent when a mold is operating on a "slow cycle" caused by handling, "lipping," transfer conditions or similar reasons with no forced cooling. The lowest inner face temperature may be near the minimum allowable for good ware while the highest inner face temperature due to the length of contact may be near the maximum allowable for the metal and glass in use. If the mold is of sufficient weight to hold a comparatively constant outside temperature, the stresses at the inner surface are at a maximum. Now, if the speed on such a set up can be increased and the maximum temperature held about the same by forced outside cooling during part of the cycle, and earlier ware removal, the minimum temperature is increased by earlier application of the succeeding "gob." The differential between maximum and minimum stress at the inner face is in this way reduced and the severity of service lessened with it.

Certain Age-Hardenable Copper Alloys

Lattice Changes Due to Heat Treatment

By L. R. VAN WERT and B. W. GONSER

Lecturer on Metallurgy, Graduate School of Engineering, Harvard University, and Metallurgist, Battelle Memorial Institute, Respectively

THE AGE-HARDENING BEHAVIOR of certain copper-nickel-silicon alloys, with particular reference to the mechanical hardness produced by various aging procedures, has been previously reported at some length by the authors[1]. This brief note supplements the earlier report in that it records some recent observations concerning changes in the spacing and the character of the X-ray line spectra in certain of the heat-treated alloys whose hardness and conductivity values were given in the original paper.

In the table are tabulated some of the earlier reported values of hardness and conductance with the particular treatment responsible in each instance; included also, in the last column of the table, are the lattice constants of a few of the heat-treated alloys as recently measured. Unfortunately, much of the lattice constant information of what would be the most interesting alloys of the series, that is to say, the partly, the fully, and the over-aged alloys, is seemingly unprocurable by the methods in common use, since a marked diffuseness characterizes the lines, making even reasonably accurate measurements impossible. Photodensitometer tracings of the films were of little assistance in locating line maxima.

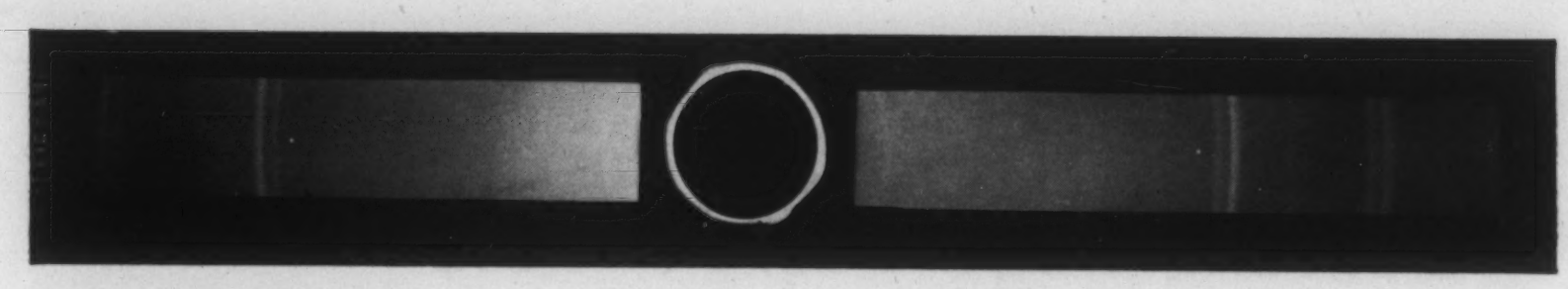
In the alloys containing about 3 per cent of the nickel silicide (for analysis of the Series B alloys, see the table), the lattice constant of the annealed and very slowly cooled alloy is 3.6085 Å, or within experimental error of the constant of pure copper which was determined to be 3.6079 Å. Apparently, the silicide is but slightly soluble in copper at room temperatures[2], (Corson[2] reports less than 0.8 per cent soluble at 300 deg C.) and the extremely slow cooling procedure left little, if any, of the silicide in solution in actual excess of the equilibrium value. The solution annealed sample, in which all of the slightly less than 3 per cent of the hardener was supposedly in solution, had a parameter of 3.6054 Å. The small difference in constant in the two conditions—a matter of about one-tenth of one per cent—is due presumably to the solution of the silicon atom in the solution annealed specimen; the nickel, likewise in solution in the copper, is less effective in its action because of its similarity to copper in the matter of atom radius.

The quenched and subsequently aged alloys of this series, excepting the one designated "partly aged," gave lines so diffuse that reliable measurements were impossible. The photodensitometer records proved to be but a little less useful except in the case of the partly aged alloy. This alloy has a measured parameter of 3.6073 Å; in the matter of unit cell size, it is thus between the dimensions of the solution and the furnace annealed samples. E. C. Bain[3], who had previously studied similar alloys by X-ray methods and had noted the marked diffuseness of the lines in the heat-treated samples, was unable to find, contrary to the results here reported, that aging produced a change in lattice constant from that found in the solution annealed or quenched alloy.

Table on Effect of Aging on Hardness, Conductivity and Lattice Constant.

Treatment	Brinell Hardness	Conductance (% of pure copper)	Lattice Constant
Series B Alloys: (Copper, 96.81%; nickel, 2.43%; silicon, 0.57%, and calculated Ni_2Si, 2.95%)			
Solution annealed (quenched from 830° C.)	56	18.27	3.6054 Å
Partly aged	142	30.13	3.6073 Å
Fully aged at 450° C.	173	40.96	.....
Over aged	113	42.40	.....
Furnace annealed (slowly cooled)	85	34.27	3.6085 Å
Series A Alloys: (Copper, 89.29%; nickel, 4.42%; aluminum, 5.31%; silicon, 0.98%, and calculated Ni_2Si, 5.07%)			
Solution annealed (quenched from 900° C.)	67	7.98	3.6294 Å
Partly aged	162	11.30	.....
Fully aged at 500° C.	214	12.07	.....
Over aged	174	12.77	.....
Furnace annealed (slowly cooled)	106	11.67	3.6331 Å

The story of the dimensional changes in the Series A alloys (containing about 5 per cent of the silicide, and in addition, about 5 per cent of aluminum) is essentially similar to, though more incomplete than, the above. The lattice constant of the furnace annealed sample is 3.6331 Å, and thus is somewhat larger than

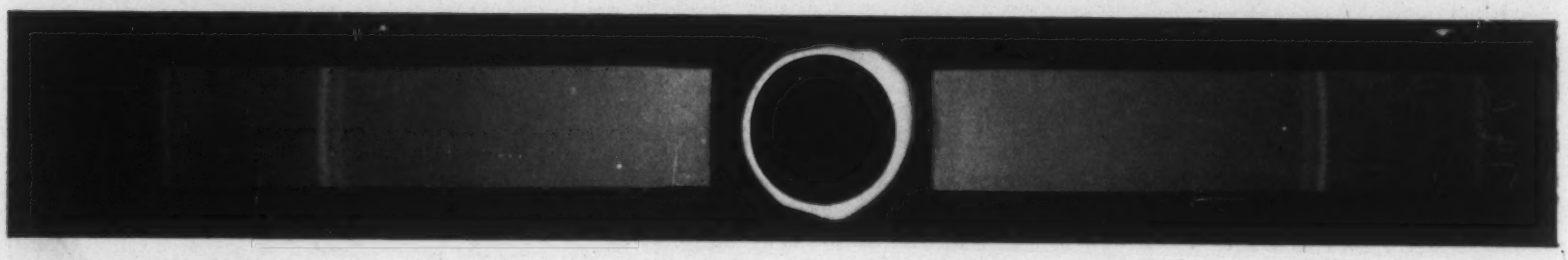


1 a

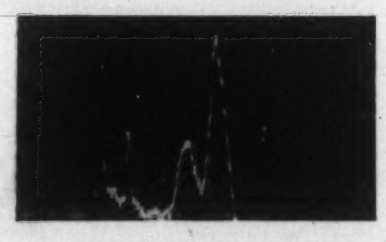
1 b

Fig. 1a. Film (Made on the Sachs' Back-Reflection Camera) of the Series A Alloy, Solution Annealed.

Fig. 1b. Photodensitometer Record of One End of this Film, Showing Well Resolved Alpha Doublet. (The maximum at the extreme right, in this and the following records, is caused by the fiducial mark placed on the original film.)



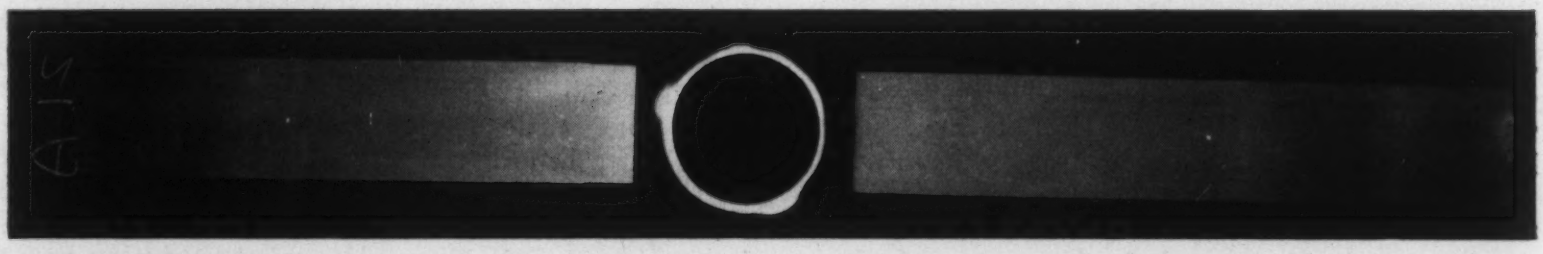
2 a



2 b

Fig. 2a. Film of the Series A Alloy, Furnace Annealed.

Fig. 2b. Photodensitometer Record of One End of this Film, Showing Well Resolved Alpha Doublet.



3 a

3 b

Fig. 3a. Film of Series A Alloy, Partly Aged.

Fig. 3b. Photodensitometer Record of One End of this Film, Showing No Resolution of the Alpha Doublet.

the corresponding sample of Series B. But the solvent of the hardener in this instance is itself a solution of 5 per cent aluminum in copper and not pure copper as in the former case. The basic lattice is consequently that of this dilute copper-aluminum solution. The change (decrease) in lattice parameter on solution annealing is, however, much the same as it was in the aluminum-free alloys, from 3.6331 to 3.6294 Å. No one of the aged specimens of this series gave a readable film.

It was unfortunate that in the aged alloys generally (in fact, in all of the alloys in which the silicide was not wholly within or wholly without the solvent lattice), the spectrum lines were too diffuse and indistinct to permit of accurate and reliable spacing measurements. This want of sharpness and definition in the diffraction pattern has, however, a certain diagnostic value, for it does indicate one peculiarity of aging behavior in these alloys, namely, that the precipitation responsible for the changes in mechanical hardness, conductivity, etc., occurs very non-uniformly, perhaps, even within a given grain. The atomic planes of any one of these grains are presumably not evenly and uniformly spaced because of local variations in the progress of the precipation phenomenon, and the reflections from these planes are, as a consequence, not so sharply focused as would otherwise be the case.

The authors wish to acknowledge the assistance given by Dr. R. R. Hultgren, instructor in metallurgy, Harvard Graduate School of Engineering, in the preparation and reading of the films.

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A Modern Batch Gas Carburizing Operation

By E. F. CONE

THE SLOWNESS OF THE HEATING in pack carburizing and the cost of heating the boxes and packing as well as the work have led to widespread adoption of carburizing with gas.

In gas carburizing one can put on a light case, suitable for many uses, and no packing is required. The process lends itself either to batch or continuous operation. A definite sequence is called for: First, heating the work to the carburizing temperature, around 1700 deg. F. (at which the steel is austenitic and able to allow rapid diffusion of carbon from the surface) in a non-oxidizing atmposhere; second, deposition of soot upon the work to supply the carbon; third, heating to allow diffusion usually maintaining the soot deposition at such a rate as to keep proper pace with diffusion, but without building up too high a carbon content at the surface of the case, or producing so thick a deposit as to form a heat-insulating coating and slow up the process.

The equipment for gas carburizing varies according to the work to be done. It must have a chamber from which air is excluded and to which the carburizing gas is admitted, means for supporting the work, for controlling temperature and gas composition, and for insuring even distribution of the gas to the work. All present gas carburizing units use some type of muffle for the chamber and heat this externally by gas or electricity. The muffle is sometimes made cylindrical, the charge dumped in, the gas passed through and uniform contact of work and gas secured by rotating the container. Unless the parts can be strung on rods to keep them from touching, which would add labor in loading, the parts tumble over each other. Hence, pieces that would be damaged by tumbling cannot well be so handled. Other batch furnaces have a vertical cylindrical retort containing a wire basket into which small parts are charged, or shelves on which larger parts are placed, and the gas is circulated by a fan.

Natural diffusion of gas, led in at the bottom and taken out through an outlet at the top, is also used, but does not give quite as rapid a rate of carburization as with forced turbulence. There is often a slight difference in depth of case between the work from the top and bottom of a vertical retort.

Other gas carburizing outfits load the work on fixtures in trays so that no two parts touch each other and run the trays into a horizontal muffle. In a continuous furnace the trays are conveyed through three zones in which the gas composition is varied in each zone, that in the preheating zone having only to be suitable for preventing oxidation, that in the sooting zone being rich in hydrocarbon, and that in the diffusion or soaking zone being less rich so as to maintain the proper rate of supply of carbon.

Where the output desired does not justify a continous furnace, or the floor space available is not sufficient for its installation, a horizontal batch furnace may be used. Here, as in the continuous furnaces,

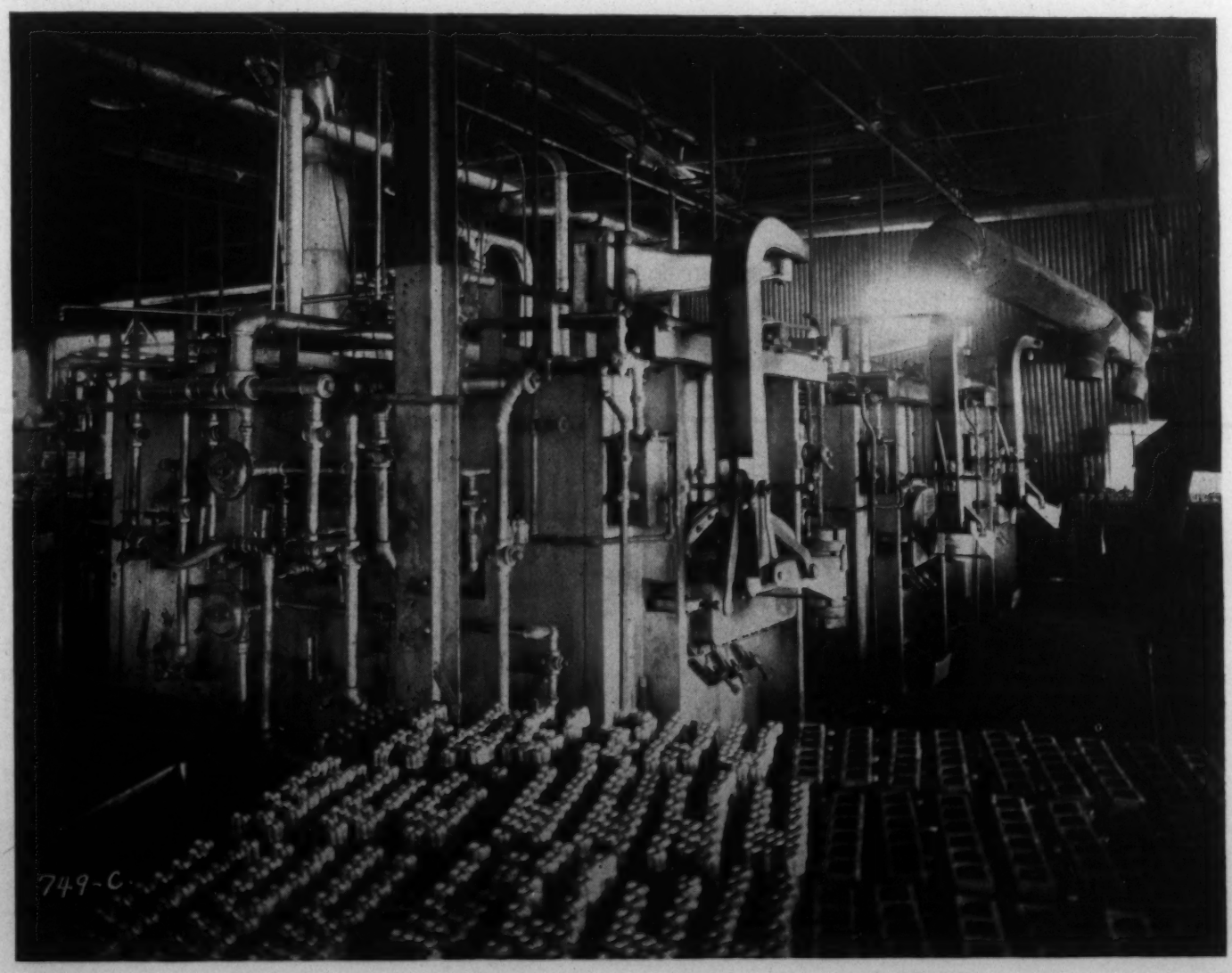

Fig. 1. Battery of Three Continuous Carburizing Furnaces at the Plant of the Electric Auto-Lite Co., Toledo, Ohio, Built by the Surface Combustion Co.

the gas atmosphere is varied through the three stages, (a) sooting, (b) carburizing, (c) diffusing. The gases used vary with the location of the plant, the source of hydrocarbon being usually natural gas where available, otherwise, manufactured gas; the same enriched by benzol, propane or butane diluted with air or flue gas, or gas formed by cracking of some oil, either cutside or inside the furnace.

Since manufactured gas may sometimes vary in composition, and the amount of moisture it carries is of importance in its carburizing action, it is preferable to utilize a gas of more certain uniformity and one of higher hydrocarbon content.

An interesting installation of the batch type of gas carburizing furnace is in operation in Toledo, where both natural gas and manufactured gas are available. This furnace, shown in Fig. 1, is at the plant of the Electric Auto-Lite Co.

The work to be carburized is clutch bodies, pinions and housings for starters where a uniform case with freedom from distortion is required. The work shown in this illustration is clutch bodies of S.A.E. 4620, weighing 6 oz. each, which are to be given an 0.028-in. case, with the usual surface carbon content of about 0.95 per cent with even gradation toward the core. Onto a heat resisting alloy tray and its fixtures, 252 bodies are loaded and 6 such trays form a furnace load. The weight of the trays and fixtures is approximately equal to the weight of the work, the gross load being about 1150 lbs. The heat resisting alloy muffle is 6½ ft. long by 29 in. wide by 8 in. high from the top of the rails to the spring of the muffle.

The trays and work having been charged into the muffle and the muffle closed, the air that has entered during charging is displaced by gas made by partly burning the city gas of about 600 B.t.u. with air in the proportions of 3 volumes of air to 1 volume of gas, in the special units shown in Fig. 2, giving a gas of about 10 per cent CO_2 2 per cent CO, 2 per cent H_2, and balance N_2. This gas is cooled in a spray tower to an approximate dew point of 70 deg. F.

This purging of the muffle and supplying of a protective atmosphere goes on for the preheating period of 1½ hrs. during which the work is brought up to a temperature of 1550 deg. F. Through this period the protective atmosphere is supplied at the rate of 50 cu. ft. per hr.

The "sooting" part of the cycle is then entered upon, the partly burnt gas being cut off and straight natural gas, analyzing CH_4 85.8, C_2H_4 3.2, C_2H_6 4.2, CO_2 0.4, N_2, 6.2, O_2 0.2 per cent, is run in for 1 hr. at the rate of 50 cu. ft. per hr.

Next the carburizing period of 2 hrs. is started, the natural gas being allowed to enter at the same rate but diluted by the addition of partly burnt gas also at at the rate of 50 cu. ft. per hr. At the end of the total period of 4½ hrs., 1½ hrs. preheat and 3 hrs. holding, the work is withdrawn and directly quenched in oil.

Proper turbulence of the gases in the muffle is obtained by injecting the gases through staggered pipes in the side of the muffle. The gases travel crosswise over the work and diffuse through the load, gradually finding their way out at the charge end of the furnace where they are exhausted through a water seal to maintain a slight positive pressure within the muffle.

The rate of carbon penetration, 0.028 in. in 3 hrs. at heat, is not quite as fast as is sometimes obtained in gas carburizing, but conditions are chosen as they are in order to make sure of the proper smooth gradation of carbon content from case to core.

The muffle is heated by low pressure city gas with burners in the side walls firing both below and above the muffle, automatic temperature control being obtained by actuation of a motor driven valve in the air line serving the burners. Both city and natural gas are available in Toledo. City gas is used for fuel and for the preparation of the partly burnt gas, but, of

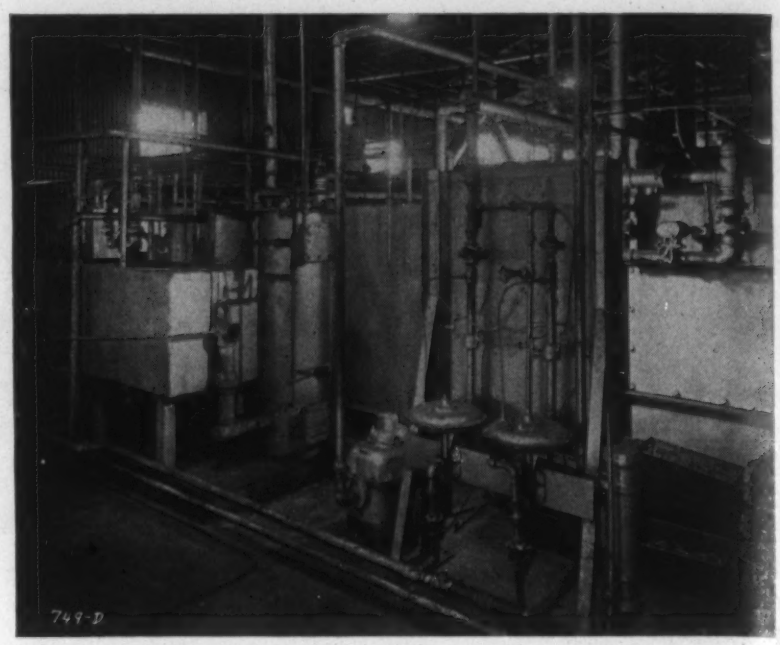

Fig. 2. Standard Unit Used in the Preparation of Carburizing Gas for Three Gas Preparation Continuous Carburizing Furnaces at the Electric Auto-Lite Plant.

course, by increasing the air ratio a similar gas could be made from natural gas, and natural gas could be used for fuel.

Carburizing costs are seldom determined with the accuracy that the costs of machine operations or of other heating processes are recorded, and figures for quite similar operations in different plants often vary 100 per cent. On the whole, it is usually figured that pack carburizing costs from 1½ to 3c per lb. of steel handled, while the various makers of batch gas carburizers, either gas fired or electrically heated, put their costs at from ½ to 1c per lb. when the work is quenched direct and figures have been given for a large continuous gas carburizing outfit, as low as 1/3 cent per lb.

Of course, batch operation should not be compared with continuous operation, and for a true comparison, it should be made on work of the same size and nature.

It is stated that the batch outfit shown in Fig. 1 carburizes clutch bodies at a cost (exclusive of interest and amortization on the furnace and gas preparation unit, but including a replacement charge on the muffle trays and fixtures) only slightly over ½c per lb. The depth of carburization is 0.028 in. in 4½ hrs. and 0.065 in. in 9 hrs. The muffle, in this calculation, is estimated to have a life of 6000 working hours. Since the clutch body weighs about 0.38 lb., the carburizing cost per piece figures about 1/5c each, which is a pretty low price to pay for a good carburizing job.

Such data would indicate pretty clearly that gas carburizing is due to replace pack carburizing at an increasing rate. However, in another plant where continuous gas carburizing replaced batch pack carburizing, the user finds the costs just about the same. This of course means that conditions vary enough in different plants to make it unsafe to assume that what is calculated for plant A may not come out just the same in plant B.

BRIGHT NICKEL PLATING

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BRIGHT NICKEL ELECTRO-DEPOSITS have been known to platers for many years. Doubtless there were many occasions, throughout the history of the plating industry, when difficulties have been encountered in buffing to a bright finish the recesses of a nickel plated part of intricate design. From many such experiences there probably emerged the idea of a bright nickel deposit which would make it unnecessary to buff the recessed portions. Some of the first results may have been obtained accidentally, through the presence of foreign materials in the baths; others at a somewhat later date were produced deliberately. Most of these early bright nickel deposits were extremely thin, very brittle and in general undesirable. Many of these deposits were formed by the use of inorganic addition agents such as zinc or cadmium.

This early work served to emphasize the fact that there was a definite need for a good bright nickel and a large field for its use, if and when, this type of deposit was made commercially successful. Within more recent years, it became known that many organic addition agents, particularly those of a colloidal nature, were very effective in brightening nickel deposits. In fact it turns out that many of them were too effective. Only relatively small amounts were required, the quantities were difficult to determine once they were in the bath, and their effects were hard to control. At the present time a variety of bright nickel baths have been, or are being, developed in various laboratories. Some of these are in commercial use. From the many bright baths which have appeared in a relatively short period of time, a few excellent ones will probably emerge.

The desirability of continued effort in perfecting such baths is evident. For steel, copper, brass, zinc and die cast articles and parts, particularly of intricate design, a plate which required no buffing would be advantageous. Recessed areas would be bright; cut-through points and thinly buffed portions would be eliminated, and final coverage should be more satisfactory in every way.

The objects to be achieved in the use of bright nickel are reduction in costs, and the production of a quality deposit which has certain definite advantages over dull nickel. To produce bright deposits, an addition agent is essential. This material, or some part of it, is often of a colloidal nature, which may act to prevent the formation of large grained deposits at the cathode. The tendency then is for the nickel deposits to be dense and fine grained. This action of the addition agent may be considered analogous to the function of a protective colloid in preventing coagulation of a colloidal dispersion, e.g., the protective action of gelatin in a photographic emulsion.

It is known that in all cases certain constituents of the addition agents or brighteners are included in small quantities in the deposit.

Characteristics of Bright Nickel

Some of the characteristics expected of a good bright nickel deposit are:

1. Excellent coverage of defects in the base metal. This is an extremely important point in bright nickel, because it is more difficult to remove defects by buffing a bright deposit than dull nickel.
2. Ductility: Lack of ductility appears to be characteristic of many bright nickel deposits. However, recent advances toward overcoming this defect look promising.
3. Uniform brightness over the plated part: This is particularly important in cases where the plated article has recessed areas which might be difficult or impossible to buff if dull nickel were used. Further, the brightness should be maintained for the thickness of plate necessary to meet modern requirements.
4. Deposits should be adherent and free from porosity. These physical properties should be expected of any nickel deposit.
5. Good protection of the base metal from corrosion is required, particularly when the bright nickel is used as the undercoat for chromium. This point, of course, is inevitably associated with lack of porosity of the nickel deposit, and with adequate thickness of plate.
6. The bright nickel deposit should be a good base for easy coverage with chromium.

Summarizing all of these characteristics: A plate which is ductile, adherent, non-porous, uniformly bright, gives good coverage of base metal defects, permits easy plating with chromium, is extremely corrosion-resistant and economical, would be the ideal plate. The objective of present research is to obtain a bright nickel which will approach the above ideal as closely as possible.

Type of Bath

One of the very important factors affecting the quality of bright plate is the type of bath used. What are the essential characteristics of a good bright nickel bath?

1. It should be easy to operate and permit a reasonably wide range of current density, temperature and pH. Operation at high current densities is advantageous. This is espeically true where the work must be done with a limited amount of equipment and floor space.
2. The bath should be simple in composition

and permit rapid and accurate analytical determination of all components, including the addition agent. A brightener whose loss of concentration can be determined only when the deposit looks dull, is of doubtful value. The inactive constituents of the brightener, as well as its decomposition products, should not interfere in any way with the proper functioning of the bath and may be readily removed from solution.

3. The bath should have good throwing power for bright plating in recesses and at points difficult of access.

4. The bath should have high efficiency.

5. The brightener or addition agent must be stable under the conditions necessary for commercial plating. Stated in another way, this means that in order to remain stable the brightener must not impose limiting conditions of operation which would be undesirable in a commercial bath.

6. The necessary amount of brightener or addition agents should be small—1 per cent or less of the solid content of the bath is desirable.

7. The cost of the brightener should be such that there will be a net reduction in the cost of the finished job, when savings brought about by the use of bright deposit are considered.

Reviewing the characteristics of the solution, it may be pointed out that there is no reason why a good bright nickel bath should be any more difficult to operate than dull nickel. In the analysis of the bath the brightening agent must not interfere with the analytical determination of nickel, chloride and boric acid. Before a commercial bright nickel is put into operation, those responsible should assure themselves that the addition agent may be readily determined in any concentration in which it may be required. Neglect of this simple detail may result in much disappointment in the results obtained. The concentration of brightener must be low, both to reduce the cost and to maintain high efficiency of the bath. In the future it is quite feasible to expect to plate bright nickel from solutions in which the total amount of addition agent is less than 0.50 per cent by weight, and the active brightener approximately one-tenth to one-fifth of this amount.

Advantages of Bright Nickel

Among the advantages of the use of bright nickel may be mentioned the production of a finer grained deposit; elimination of cut through and thin sections due to buffing; reduction in the number of shop scratches, and the increased opportunity of plating very intricate articles with bright finishes. In addition it may be pointed out that it should be possible on some work to rinse and chromium plate without reracking. If no additional metal above the amount finally desired must be deposited, to be later removed by buffing, a saving of both metal and time will result. Bright nickel deposits are in general harder than dull nickel. For those many parts in which flexibility of the deposit is not an essential factor, a hard dense nickel would be as good if not better than a softer coating.

Bright nickel baths have at times yielded poor results. Lax operation may have been in part responsible for some of the difficulty. In the past, deposits in general have shown a tendency to be more brittle than dull deposits. Recent work has indicated improvement of this defect. In some cases brightening agents have not been found to be of the requisite stability. The use of bright nickel requires good electrical contacts and excellent racking in order to get the desired throwing power. However, from the standpoint of the necessity for proper rack maintenance, this should be considered as an advantage. Up to the present time it has generally been necessary to prepare the work more carefully for bright nickel plating than for dull nickel. This includes greater care both in polishing and cleaning. However, this may be considered an advantage from the standpoint of quality results.

Many in the plating industry are of the definite opinion that bright nickel is here to stay. The possibilities for the wide use of a commercially successful bath are constantly increasing. The extension of its use will be limited only by the ability of these baths to produce the type of results desired at an economic saving.

It is to be hoped that the time is not far distant when the use of bright nickel will make it feasible to carry the plating operation through to the chromium with no intervening inspections.